A hybrid low bit-rate video codec using subbands and statistical modeling

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A hybrid low bit-rate video codec using subbands and statistical modeling is proposed in this thesis. The redundancy within adjacent video frames is exploited by motion estimation and compensation. The Motion Compensated Frame Difference (MCFD) signals are decomposed into 7 subbands using 2-D dyadic tree structure and separable filters. Some of the subband signals are statistically modeled by using the 2-D AR(1) technique. The model parameters provide a representation of these subbands at the receiver side with a certain level of error. The remaining subbands are compressed employing a classical waveform coding technique, namely vector quantization (VQ).

It is shown that the statistical modeling is a viable representation approach for low-correlated subbands of MCFD signal. The subbands with higher correlation are better represented with waveform coding techniques.
A HYBRID LOW BIT-RATE VIDEO CODEC USING SUBBANDS AND STATISTICAL MODELING

by

Ferhat Cakrak

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2 MOTION COMPENSATED VIDEO CODING</td>
<td>3</td>
</tr>
<tr>
<td>2.1 Introduction</td>
<td>3</td>
</tr>
<tr>
<td>2.2 Block Matching Algorithm (BMA)</td>
<td>5</td>
</tr>
<tr>
<td>2.3 The Motion Compensated Frame Difference Signal (MCFD)</td>
<td>8</td>
</tr>
<tr>
<td>3 STATISTICAL MODEL BASED IMAGE CODING TECHNIQUES</td>
<td>10</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>10</td>
</tr>
<tr>
<td>3.2 Autoregressive (AR) Process</td>
<td>10</td>
</tr>
<tr>
<td>3.3 First-order Autoregressive AR(1) Process</td>
<td>12</td>
</tr>
<tr>
<td>3.4 First-Order Correlation Models for Images</td>
<td>14</td>
</tr>
<tr>
<td>3.4.1 First-Order Autoregressive AR(1) Source Model for Images</td>
<td>15</td>
</tr>
<tr>
<td>4 THEORY OF SUBBAND SIGNAL ANALYSIS AND FILTER BANKS</td>
<td>18</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>18</td>
</tr>
<tr>
<td>4.2 Main Building Blocks in Subband Analysis</td>
<td>18</td>
</tr>
<tr>
<td>4.2.1 Downsamplers and Upsamplers</td>
<td>18</td>
</tr>
<tr>
<td>4.2.2 Anti-aliasing Filters</td>
<td>20</td>
</tr>
<tr>
<td>4.2.3 Interpolation Filters</td>
<td>21</td>
</tr>
<tr>
<td>4.3 Two Channel Perfect Reconstruction Quadrature Mirror Filter (PR--QMF) Banks</td>
<td>21</td>
</tr>
<tr>
<td>4.4 M-Band Tree Decomposition</td>
<td>25</td>
</tr>
<tr>
<td>4.5 Two Dimensional Separable Case</td>
<td>26</td>
</tr>
<tr>
<td>5 VECTOR QUANTIZATION IN SUBBANDS</td>
<td>31</td>
</tr>
<tr>
<td>5.1 Introduction</td>
<td>31</td>
</tr>
<tr>
<td>5.2 Vector Quantization</td>
<td>31</td>
</tr>
<tr>
<td>5.3 Codebook Design</td>
<td>32</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2.1</td>
<td>Block Diagram of Motion Compensated Video Sequence Coding Structure.</td>
</tr>
<tr>
<td>2.2</td>
<td>Block matching motion estimation</td>
</tr>
<tr>
<td>2.3</td>
<td>Frame by frame variation of the correlation coefficients for the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>2.4</td>
<td>Frame by frame variation of variances for the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>3.1</td>
<td>Filter Model of AR(N) Process</td>
</tr>
<tr>
<td>3.2</td>
<td>Filter Model of AR(1) Process</td>
</tr>
<tr>
<td>3.3</td>
<td>Frame by frame variation of variances for the LH band of the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>4.1</td>
<td>Block diagrams for downsampler and upsampler</td>
</tr>
<tr>
<td>4.2</td>
<td>Downsampling with M=2</td>
</tr>
<tr>
<td>4.3</td>
<td>Upsampling with M=2</td>
</tr>
<tr>
<td>4.4</td>
<td>Frequency domain representation of the Upsampling by 2, with the input signal (top) and the upsampled signal (bottom).</td>
</tr>
<tr>
<td>4.5</td>
<td>Frequency domain representation of the downsampling by 2, with the input signal (top) and the downsampled signal (bottom).</td>
</tr>
<tr>
<td>4.6</td>
<td>Interpolation and decimation filters.</td>
</tr>
<tr>
<td>4.7</td>
<td>The two-channel QMF bank</td>
</tr>
<tr>
<td>4.8</td>
<td>4 band regular tree decomposition.</td>
</tr>
<tr>
<td>4.9</td>
<td>7 band dyadic tree decomposition.</td>
</tr>
<tr>
<td>4.10</td>
<td>4 band regular tree decomposition and reconstruction of a 2-D signal x(m,n)</td>
</tr>
<tr>
<td>4.11</td>
<td>7 band dyadic tree decomposition and reconstruction of a 2-D signal x(m,n) using 2-D separable filters</td>
</tr>
<tr>
<td>5.1</td>
<td>Illustration of clusters and the vector quantization for two-dimensional space.</td>
</tr>
<tr>
<td>5.2</td>
<td>2-D subbands used in video codec</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>6.1</td>
<td>Frequency responses of the 8 tap separable low-pass and high-pass filters.</td>
</tr>
<tr>
<td>6.2</td>
<td>Frame by frame variation of the average $SNR_{pp}$ values in dB for the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>6.3</td>
<td>Frame by frame variation of the first order entropy values for the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>6.4</td>
<td>Frame by frame variation of the average $SNR_{pp}$ values in dB for the test sequence &quot;TOPGUN&quot;</td>
</tr>
<tr>
<td>6.5</td>
<td>Frame by frame variation of the first order entropy values for the test sequence &quot;TOPGUN&quot;</td>
</tr>
<tr>
<td>6.6</td>
<td>25th frame of the test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>6.7</td>
<td>The direct difference between the frames 25 and 26 of test sequence &quot;CINDY&quot;</td>
</tr>
<tr>
<td>6.8</td>
<td>26th frames of the test sequence &quot;CINDY&quot;, the original (top) and coded (bottom) ($SNR_{pp} = 34.1$, $bpp = 0.24$)</td>
</tr>
<tr>
<td>6.9</td>
<td>26th MCFD frames of &quot;CINDY&quot;, the original (top) and coded (bottom) ($SNR_{pp} = 34.1$, $bpp = 0.24$)</td>
</tr>
<tr>
<td>6.10</td>
<td>LH band of the 26th MCFD frames of &quot;CINDY&quot;, the original (top) and statistically modeled (bottom).</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Interest in digital image processing has significantly increased over the past two decades. Advances in signal and image processing techniques allow sophisticated image processing algorithms to be realized in real time at a reasonable cost. However, the storage capacity and bandwidth of available communication channels have always been two major limitations. Since the amount of data in images is immense the compression of data has been of a great interest. Hence, there have been several image compression techniques proposed in the literature and the problem is still being actively pursued.

In video transmission and storage applications, one mostly has to deal with the images of moving objects. The motion occurring in such a multi-frame sequence is due to translation and rotation of objects with respect to the camera or moving camera and moving object case[1].

In video frames, we encounter the redundancy in temporal and spatial dimensions among the adjacent frames. A satisfactory data compression technique should not only remove temporal and spatial redundancies but also give a good visual perspective for a certain level of image quality [1]. The more visual quality we can sacrifice, the lower the bit-rate we need to transmit or to store an image.

There are several video coding techniques which provide satisfactory performance for compression. Most of these techniques employ transform coding of motion prediction error which is also known as the motion compensated frame difference (MCFD) signal. The MCFD signal has been studied by several researchers and it is still being studied extensively in order to achieve better compression and visual performance. The statistical model based and subband coding techniques are the ones combined in the proposed codec structure of this thesis.
In model based image coding, an image or some regions of an image are statistically modeled and the model parameters are used for the representation. At the transmitter, the the statistical model parameters are estimated by analyzing the image. Then, these parameters are quantized and sent to receiver side. At the receiver side, the image is reconstructed using quantized model parameters. Although the modeling of speech is useful and works well, the modeling of images has not been satisfactory. Therefore, model-based image coding technique is still at the research stage and more needs to be done[3].

Subband coding, one of the most powerful waveform coding techniques, has found its applications in speech and image processing. To compress the data, the signal is divided into a set of uncorrelated frequency bands and subband signals are encoded after an optimal bit allocation.

In this thesis, the MCFD signal is studied by using subband coding and statistical modeling in subbands.

Chapter 2 deals with the motion compensated video coding and the statistical evaluation of MCFD signals. In Chapter 3, autoregressive source models and AR(1) modeling are studied. Chapter 4 deals with the theory of subband signal analysis and filter banks. In Chapter 5, vector quantization in subbands is covered. In Chapter 6, the experimental results are presented. The conclusions are given in Chapter 7.
CHAPTER 2

MOTION COMPENSATED VIDEO CODING

2.1 Introduction

In this chapter, the general idea behind the motion compensated video coding technique is given. The algorithms used for prediction are classified and explained briefly. In Section 2.2, the theory of block matching algorithms is given in detail. Section 2.3 deals with the statistical features of motion compensated frame difference (MCFD) signals.

Any good video coding technique should remove not only the temporal but the spatial redundancies. To eliminate redundancy in a video sequence, interframe predictive coding, one of the most powerful video coding techniques, is widely used. In a typical interframe coding process, the present video frame is predicted based on frame to frame motion and the previous frame. The prediction error, MCFD, along with motion information is transmitted. At the receiver side, the MCFD signals are decoded and added to the motion based prediction of the frame. The main feature in this coding technique is to predict the current frame based on the previous one. The better prediction gives the smaller error signal and the smaller transmission bit rate [2].

The video scenes usually contain moving objects. The motion in a typical video sequence is due to the rotation and translation of the objects. The current frame $F_K$ is predicted by using the previous frame $F_{K-1}$ and frame to frame motion. This process is called motion compensation, and the difference between the current frame and its motion compensated prediction is called motion compensated frame difference (MCFD) signal. Block diagram of motion compensated video coding technique is given in Figure 2.1.
Figure 2.1 Block Diagram of Motion Compensated Video Sequence Coding Structure.

To predict the current frame by using the previous frame, there are several motion estimation algorithms proposed in the literature. Most common algorithms used in practice are as follows:

- **Block Matching Algorithm**
- **Pel (pixel) Recursive Algorithm**
- **Knowledge Based Algorithm**

First two algorithms use the 2D information of the successive video frames. The block matching algorithm tries to estimate the displacement vectors by means of comparing the gray levels of adjacent video frames in block fashion. On the other hand, pel recursive algorithm uses the coded neighbour pixels to predict the
displacement of each pixel\([2]\). These two algorithms are based on the following assumptions:

- The motion of the moving objects is only translation.
- Intensity (illumination) is the same in spatial and temporal dimensions.
- Masking between objects and uncovered background is neglected.

The knowledge based algorithm employs the 3-D motion constraints. Although this algorithm is quite popular in model based coding, it is not quite practical due to the computational load and complexity of the algorithm.

2.2 Block Matching Algorithm (BMA)

In the current technology, block matching algorithms are widely used due to their simplicity and effectiveness. The block matching algorithm (BMA) divides an image into fixed or variable size rectangular blocks, and assumes that each block can be represented by a displacement vector \(D = (d_x, d_y)\) as shown in Figure 2.2. In order to maintain the validity of the assumption, block sizes are kept small, such as 8x8 or 16x16\([2]\).

In this study, the motion compensation is based on the block matching algorithm, which can be implemented by using fixed or variable size blocks. In our approach, each video frame is divided into 8x8, fixed size, blocks. Each 8x8 block in current frame is compared with all possible blocks within a certain search region in the previous frame. The best matching block is found by the following procedure.

The motion detector compares each pixel of a predefined image block in the present frame \(K\), with the corresponding pixel values of the previous frame \(K - 1\). If the condition given by Eq. 2.1 is satisfied, which means difference is above the predetermined threshold value, then the pixel \(m, n\) of block \(i, j\) in frame \(K\) is assumed moving. For an 8x8 block, if the number of moving pixels is above the predetermined
threshold value $N_0$ as given in Eq.2.2, then that block is assumed moving.

$$|P_{ij}^K(m, n) - P_{ij}^{K-1}(m, n)| \geq T_0 \quad m, n = 1, 2, \ldots, 8$$ \hspace{1cm} (2.1)

$$\text{[number of moving pixels in an 8x8 block]} \geq N_0 \hspace{1cm} (2.2)$$

$T_0$ and $N_0$ are the predefined threshold values for each pixel and each 8x8 block respectively. These values can be adjusted depending on the application. In this study, $T_0 = 3, N_0 = 10$, have been found suitable values for the experimental video sequences. If the block has a motion, then motion estimation and compensation procedure is performed.

The BMA tries to find the best match for each 8x8 block belonging to the present frame $K$, using a predefined search region in the previous video frame. Predefined search region size has been taken as $(8 + 2p)x(8 + 2p)$ and fixed. It is assumed that the maximum displacement between two 8x8 blocks in two consecutive video frames is $\mp p$ pixels in two dimensions. For a video conferencing environment $p = 6$ is used. There are $(2p + 1)x(2p + 1)$ different blocks in search region in which each block is a candidate to be the correct displacement.
A comprehensive search algorithm scans all the candidate search points in the search area for the best match. The best match is found by minimizing the distortion measurement, like mean square error (MSE), or by maximizing a correlation feature, like the cross-correlation function, of the two blocks [2]. In practice, there are several fast search algorithms. Independent orthogonal search algorithm, a computationally efficient search algorithm, is used in this study [1].

Number of thresholded absolute difference (NTAD) given in Eq.(2.3) is employed as the objective function.

\[
NTAD_{k,l} = \sum_{m=1}^{8} \sum_{n=1}^{8} \left[ f(T_1, |B_{i,j}^K(m,n) - S_{i,j}^{K-1}(m+k,n+l)|) \right] \quad k, l = 1, 2, ..., 13 \quad (2.3)
\]

where

\[
f(T_1, D) = \begin{cases} 
1 & T_1 \leq D \\
0 & T_1 > D 
\end{cases}
\]

and \(S_{i,j}^{K-1}\) is the search region for block \(B_{i,j}^K(m,n)\). The best match is found by minimizing \(NTAD(k,l)\). The parameter value \(T_1 = 3\) is found the best for the video sequences used in this study.

After determining the best match, the image block \(B_{i,j}^K\) is predicted as \(\hat{B}_{i,j}^K\) based on the corresponding 8x8 block in the previous video frame \(F_{K-1}^K\). This process is repeated for all the blocks and the prediction of the current frame \(\hat{F}_K^K\) is obtained as seen in Figure 2.1.

The prediction error, which is basically the difference signal between the original frame and its prediction, is encoded and transmitted to the receiver side along with the motion information to reconstruct the current frame \(F_K^N\). The prediction error which is also called motion compensated frame difference (MCFD) signal is given in Eq.(2.4) for the \(MXN\) video image sequences.

\[
MCFD_K(i,j) = F_K(i,j) - \hat{F}_K(i,j) \quad \text{for} \quad i = 1, \ldots, M \\
j = 1, \ldots, N
\]
2.3 The Motion Compensated Frame Difference Signal (MCFD)

Although the motion information of the motion compensated video coding technique has to be encoded lossless, the MCFD signal may be encoded by using any entropy reduction technique. Transform coding, hybrid coding, and some other source coding techniques have been used to encode the MCFD signals.

It is well known that the performance of the transform coding decreases significantly for the low correlated signal sources such as MCFD signals. Therefore, transform coding is not a good choice for this kind of signals[1]. For the video test sequence "CINDY", frame by frame variation of the average first order horizontal and vertical correlation coefficients are given in Figure 2.3. It is seen from the figure that MCFD signals are low correlated.
Figure 2.4 Frame by frame variation of variances for the test sequence "CINDY"

The variance of the \textit{MCFD} signals for first forty frames of the test sequence are displayed in Figure 2.4. It is seen that variance of the motion compensated frame difference signal for the first forty frames of the test sequence "CINDY" is just about 25\% of the direct frame to frame difference signal.

There are several contributors to the prediction error (MCFD) signal. All types of motion is approximated by translation. Additionally, using the encoded version of previous frame for prediction brings the effects of the quantization noise into the progress. Furthermore, the threshold values used, $T_0$, $T_1$, $N_0$, are not global optimum values. Last, no abrupt scene change is included in this study. Hence, the effects of abrupt scene changes are not seen here.
CHAPTER 3

STATISTICAL MODEL BASED IMAGE CODING TECHNIQUES

3.1 Introduction

It is highly desirable to define signal sources by a set of statistical parameters. These parameters are used in transmission and storage applications for modeling of source characteristics. The main objective here is to use as few parameters as possible to represent a signal source, keeping certain level of signal quality for a given application. As mentioned earlier in Chapter 1, in statistical model based image coding, an image or a portion of it is statistically modeled and model parameters are quantized and sent to the receiver side to reconstruct the image. Although the statistical modeling works well in speech coding applications, it does not give satisfactory results in still frame image coding applications. Therefore, it is still an active research area and more needs to be done.

Autoregressive modeling is widely used in 1-D applications like linear predictive coding (LPC) of speech. Although its performance is not satisfactory for 2-D applications, like still frame image modeling, it is a reasonable technique to represent MCFD signals. Hence, it can be used for modeling of the MCFD signals, i.e., by employing the subband coding technique some frequency bands of the MCFD signal can be statistically modeled.

In this chapter, Section 3.2 covers autoregressive (AR) processes. In Section 3.3, first-order autoregressive, AR(1), process is studied. In Section 3.4, AR(1) modeling technique for images and the statistics of test images are presented.

3.2 Autoregressive (AR) Process

An autoregressive (AR) process is generated by passing the white noise $\eta(n)$ innovations through an all-pole filter. A wide-sense zero-mean white noise process
Figur 3.1 Filter Model of AR(N) Process

and its spectrum are defined as:

\[ S_{NN}(e^{j\omega}) = \sigma_N^2 \] (3.1)

where \( \sigma_N^2 \) is the variance of a zero mean, wide-sense stationary white noise sequence. Its autocorrelation sequence is given as

\[ R_{NN}(m) = E[\eta(n)\eta(n+m)] = \sigma_N^2 \delta(m) \] (3.2)

where

\[ \delta(m) = \begin{cases} 1 & \text{for } m = 0 \\ 0 & \text{otherwise} \end{cases} \]

is the kronecker delta function. For any shift \( m \) there is no correlation between the samples of the white noise process and it has a flat power spectral density function as seen in Eq.(3.1).

Filter used in this process is called all-pole since it has \( N \) multiple zeros at \( z=0 \) as seen in Eq.(3.3),

\[ H(z) = \frac{1}{1 - \sum_{i=1}^{N} b_i z^{-i}} = \frac{z^N}{z^N - \sum_{i=1}^{N} b_i z^{N-i}} \] (3.3)
The difference equation generating the AR process \( \{ x(n) \} \) is given by

\[
x(n) = \eta(n) + \sum_{i=1}^{N} b_i x(n - i)
\]  

(3.4)

The process \( \{ x(n) \} \) is called AR(\( N \)) or Nth order Markov process. \( \{ b_i \} \) are the correlation coefficients. The filter model realizing an AR(\( N \)) process is given in Figure 3.1.

The impulse response of an all-pole filter is in infinite duration. However, the autocorrelation function (acf) can be calculated recursively for the given set of prediction coefficients \( b_i ; i = 1, 2, \ldots, N \). This is done by multiplying \( x(n) \) in Eq.(3.4) with \( x(n - m) \) and taking the expectations of both sides. Here, we should note that the white noise innovations \( \eta(n) \) are uncorrelated with its past outputs by definition. As a result, we have the following equations

\[
E[\eta(n)x(n - m)] = 0 \quad \text{for} \quad k > 0
\]  

(3.5)

where \( E[.] \) donates expectation and

\[
\sigma_x^2 = E\{|x(n)|^2\} = R_{xx}(0) = \sum_{i=1}^{N} b_i R_{xx}(i) + \sigma_{\eta}^2
\]  

(3.6)

where \( \sigma_x^2 \) is the signal power. The recursive relation of autocorrelation sequence is given as

\[
R_{xx}(m) = \sum_{i=1}^{N} b_i R_{xx}(m - i) \quad m > 0
\]  

(3.7)

The all-pole model leads to \( N \) unknowns and \( N \) linear equations. These equations can be solved by using Levinson algorithm or the Cholesky decomposition[4][5].

### 3.3 First-order Autoregressive AR(1) Process

The first-order Markov or AR(1) process, with zero mean, is obtained easily from Eq.(3.4) with \( N=1 \) and \( b_1 = \rho \). Thus, we have the difference equation of AR(1) source model in time as
where $\rho$ is the first order correlation or prediction coefficient and $\{\eta(n)\}$ is the white noise sequence as given in Eqs.(3.1) and (3.2). The corresponding first-order filter function is found as

$$H(z) = \frac{1}{1 - \rho z^{-1}}$$  (3.9)

with the frequency response

$$H(e^{j\omega}) = H(z)_{z=e^{j\omega}} = (1 - \rho e^{-j\omega})^{-1}$$  (3.10)

and the unit sample response

$$h(n) = \rho^n \quad n = 0, 1, \ldots \ldots$$  (3.11)

The filter diagram for the first-order autoregressive process is given in Figure 3.2 where $b_1$ denotes the first-order correlation or prediction coefficient.

The autocorrelation function of an AR(1) signal is found as

$$R_{xx}(m) = \sigma_x^2 \rho^{|m|} \quad m = 0, \pm 1, \pm 2, \ldots$$  (3.12)

The signal variance is expressed as

$$\sigma_x^2 = R_{xx}(0) = \frac{\sigma_N^2}{1 - \rho^2}$$  (3.13)
where $\sigma_N^2$ is the noise variance.

The power spectral density (psd) of an AR(1) process is given by

$$S_{xx}(e^{j\omega}) = \sigma_N^2 |H(e^{j\omega})|^2 = \frac{1 - \rho^2}{1 + \rho^2 - 2\rho \cos \omega} \sigma_X^2$$

(3.14)

The process generated by Eq.(3.8) is stationary if the filter is stable. Therefore, $|\rho| < 1$ and

$$\sum_{n=0}^{\infty} |h(n)| = (1 - |\rho|)^{-1} < \infty$$

(3.15)

Otherwise, a non-stationary process results.

The AR(1) source model is a good analytical tool in a variety of applications, such as speech and statistical model based signal representation.

### 3.4 First-Order Correlation Models for Images

A random field in which the mean is independent of spatial coordinates and the autocorrelation function is translation-invariant is called homogeneous. Properties of an homogeneous field is described by

$$E\{m,n\} = \mu(m,n) = \text{constant}$$

(3.16)

$$E\{x(m,n)x(m+k,n+l)\} = R_{xx}(m,n) \text{ for all } m,n$$

(3.17)

A homogeneous random field is white-sense stationary with the following power spectral density and autocorrelation function descriptions;

$$S_{xx}(e^{j\omega_1}, e^{j\omega_2}) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} R_{xx}(m,n)e^{-j\omega_1 m}e^{-j\omega_2 n}$$

(3.18)

$$R_{xx}(m,n) = \left[ \frac{1}{2\pi} \right]^2 \int_{-\pi}^{\pi} \int_{-\pi}^{\pi} S_{xx}(e^{j\omega_1}, e^{j\omega_2})e^{j\omega_1 m}e^{j\omega_2 n} \; d\omega_1 d\omega_2$$

(3.19)

If all the values of $R_{xx}(m,n)$ are zero in both spatial directions except $R_{xx}(0,0)$, a white noise process results. The autocorrelation function of a white noise process is defined by
The process has a flat power spectral density (psd) function as given in Eq.(3.21).

\[ S(e^{j\omega_1}, e^{j\omega_2}) = \sigma_N^2 \]  (3.21)

The correlation models in two dimensional sources are divided into two groups; separable and non-separable correlation models[4]. Experimental studies have indicated that natural objects are better represented by non-separable correlation models[5]. On the other hand, artificial images are better represented by the separable correlation models. In this study, separable correlation model is employed. Hence, we are only concentrated on 2-D AR(1) modeling. More information about 2-D correlation models can be found in references [4] and [5].

### 3.4.1 First-Order Autoregressive AR(1) Source Model for Images

An important autocorrelation model in two dimensions is the first-order autoregressive AR(1) source model which has the autocorrelation function

\[ R_{xx}(m,n) = \sigma_x^2 \rho_{m, n} \]  \( m,n = 0, \mp, 1, \mp, 2, \ldots \)  (3.22)

and variance

\[ \sigma_x^2 = R_{xx}(0,0) = \frac{\sigma_N^2}{(1 - \rho_h^2)(1 - \rho_v^2)} \]  (3.23)

where m and n are spatial shifts in horizontal and vertical directions, and \( \rho_h \) and \( \rho_v \) are the corresponding first-order horizontal and vertical correlation coefficients, respectively. The correlation model in Eq.(3.22) is called separable because it can be expressed as the product of two one-dimensional autocorrelations. One can verify that

\[ R_{xx}(m,n) = \sigma_x^2 \rho^{[m]|n|+|n|} \]  \( i \not\in \{ \rho_h = \rho_v = \rho \)  (3.24)
A 2-D AR(1) signal can be expressed by the difference equation

\[ x(m, n) = \rho_h x(m - 1, n) + \rho_v x(m, n - 1) - \rho_h \rho_v x(m - 1, n - 1) + \eta(m, n) \quad (3.25) \]

where \( \{\eta(m, n)\} \) is the zero mean, white noise array with the variance \( \sigma_N^2 \). The transfer function of 2-D AR(1) filter in Z-domain is given as

\[ H(z_1, z_2) = \frac{1}{1 - \rho_h z_1^{-1} - \rho_v z_2^{-1} - \rho_h \rho_v z_1^{-1} z_2^{-1}} \quad (3.26) \]

Although the real-world images are not stationary, they can be assumed stationary over a small region. By using this assumption, statistical parameters namely \( \rho_h, \rho_v, \sigma^2_x \) and \( \mu(m, n) \) of each region can be estimated, and these parameters can be used for image representation.

In this thesis, the first-order autoregressive source model is used for the statistical modeling of the MCFD frame in the subbands.

First, the MCFD signal is decomposed into a set of frequency bands (4 and 7 band 2-D filter banks) and then, some of the subband signals are modeled by using AR(1) technique. The following steps are performed for each subband.

The MCFD subband frame is divided into fixed size blocks, i.e., 8x8, 4x4, and for each block, the mean is calculated and subtracted from the respective block. Then, the statistical model parameters, namely \( \rho_h, \rho_v \) and \( \sigma^2_x \), are estimated for each zero mean block. These 4 parameters are quantized and encoded for transmission. At the receiver side, these parameters are used to reconstruct the corresponding image blocks by using Eq.(3.25). The white noise array \( \eta(m, n) \) is generated by using the respective local block variances with zero mean. The relationship between local block variances and white noise array variances is given in Eq.(3.23).

After reconstructing each statistically modeled, zero mean, block, mean is added to each respective block to recover the statistically modeled MCFD subband frame.
It is obvious that even in the case of perfect quantization, original signal cannot be recovered. Modeling brings some error due to stationarity assumption. Frame by frame average variances of the LH band before and after AR(1) modeling is given in Figure 3.3 for the first forty frames of the test sequence "CINDY" for 4x4 block size.

Figure 3.3 Frame by frame variation of variances for the LH band of the test sequence "CINDY"
CHAPTER 4
THEORY OF SUBBAND SIGNAL ANALYSIS AND FILTER BANKS

4.1 Introduction

In recent years, subband coding has been widely used for image and video coding applications. To compress the data, the signal is decomposed into a set of uncorrelated frequency bands and each of these subband signals are encoded for transmission after the optimal bit allocation. At the receiver side these encoded subband signals are decoded to reconstruct the signal.

In general, a subband system can be decomposed into two parts, analysis and synthesis. The analysis part of a subband system consists of anti-aliasing subband filters and downsamplers. The synthesis part consists of upsamplers and interpolation filters.

In this chapter, section 4.2 deals with the main building blocks of a subband system, i.e., downsamplers, upsamplers, anti-aliasing and interpolation filters. The two channel perfect reconstruction quadrature mirror filter (PR-QMF) banks are studied in section 4.3. In section 4.4, M-band tree decomposition is covered along with 4 and 7 band filter banks. Section 4.5 deals with the two dimensional separable filter case which is used in this study.

4.2 Main Building Blocks in Subband Analysis

In this section, main building blocks, i.e., downsamplers, upsamplers, anti-aliasing and interpolation filters, are studied along with their frequency domain characterizations.

4.2.1 Downsamplers and Upsamplers

Figure 4.1 shows the block diagrams of a downsampler and upsampler. The input-output relation of a downsampler with rate M is given by[6]
Eq. (4.1) shows that the output at time $n$ is equal to the input at time $Mn$. As a result, only the input samples with the sample numbers equal to multiples of $M$ are retained. The sampling rate reduction process is illustrated in Figure 4.2 for $M = 2$ case.

The input–output relation of an $M$-fold upsampler is given by

$$y(n) = x(Mn). \quad (4.1)$$

Eq. (4.2) indicates that the output $y(n)$ is obtained by inserting $M - 1$ zeros between adjacent samples of $x(n)$. This process is shown in Figure 4.3 for $M = 2$.

Although the downsamplers and upsamplers make the system time varying, they are linear systems.

The transform domain description of the upsampler is given by

$$Y(z) = X(z^M), \quad Y(e^{j\omega}) = X(e^{jM\omega}) \quad (4.3)$$

where $z = e^{j\omega}$. The stretching effect of upsampling in time domain corresponds to a compression in frequency domain as shown in Figure 4.4 for $M = 2$. As seen from the figure, $Y(e^{j\omega})$ has $M - 1$ images of the basic spectrum. Consequently, the upsampler causes an imaging effect.
The transform domain description of the downsampler is given by

\[ Y(Z) = \frac{1}{M} \sum_{k=0}^{M-1} X(Z^{1/M}W^k), \quad Y(e^{j\omega}) = \frac{1}{M} \sum_{k=0}^{M-1} X(e^{j(\omega-2\pi k)/M}) \]  

(4.4)

where \( W = e^{-2\pi j/M} \). For \( M = 2 \), this equation becomes

\[ Y(e^{j\omega}) = \frac{1}{2}[X(e^{j\omega/2}) + X(e^{j\omega/2})] \]  

(4.5)

As seen above, a downsampler causes compression in time and brings the stretching effect in frequency domain as shown in Figure 4.5 for \( M = 2 \). Figure 4.5 also shows that spectrum of the original signal after downsampler contains the \( 2\pi \)-shifted versions of the original spectrum. As a consequence, aliasing effect is observed.

### 4.2.2 Anti-aliasing Filters

To avoid the aliasing effect of downsampling operation, the downsampler is preceded by a band limiting filter which is called anti-aliasing or decimation filter. For example, a low-pass filter with the stopband edge \( \omega_s = \frac{\pi}{M} \) can serve as such a filter for the signal downsamled by \( M \) as seen in Figure 4.6.
4.2.3 Interpolation Filters

To eliminate the imaging effects at the output of the upsampler, it is followed by an interpolation filter. The low-pass filter in figure 4.6, again, may serve as an interpolation filter.

4.3 Two Channel Perfect Reconstruction Quadrature Mirror Filter (PR-QMF) Banks

Consider the two channel QMF structure given in Figure 4.7. Based on the Eqs. (4.3) and (4.5), we can express $\hat{X}(Z)$ as [7]

$$
\hat{X}(Z) = \frac{1}{2} [H_0(Z)F_0(Z) + H_1(Z)F_1(Z)]X(Z) + \frac{1}{2} [H_0(-Z)F_0(Z) + H_1(-Z)F_1(Z)]X(-Z)
$$

(4.6)
Figure 4.4 Frequency domain representation of the Upsampling by 2, with the input signal (top) and the upsampled signal (bottom).

The second term in Eq.(4.6) represents the effects of imaging and aliasing. These terms can be eliminated simply by choosing the synthesis filters to be

\[ F_0(Z) = H_1(-Z), \quad F_1(Z) = -H_0(-Z) \] (4.7)

When the aliasing effect is eliminated, the QMF bank becomes a time-invariant system with the transfer function

\[ T(Z) = \frac{\hat{X}(Z)}{X(Z)} = \frac{1}{2} \left[ H_0(Z)H_1(-Z) - H_1(Z)H_0(-Z) \right] \] (4.8)

Ideally, \( T(Z) \) is desired to be a delay, i.e., \( T(Z) = Z^{-n_0} \), so that the reconstructed signal is a delayed version of \( x(n) \). Unfortunately, \( T(Z) \) is not a delay in general and it represents a distortion overall transfer function. One can express \( T(Z) \) in the form of

\[ T(Z) = T(e^{j\omega}) = |T(Z^{j\omega})| \text{ arg}[T(e^{j\omega})] \] (4.9)
Figure 4.5 Frequency domain representation of the downsampling by 2, with the input signal (top) and the downsampled signal (bottom).

where $|T(e^{j\omega})|$ and $\arg[T(e^{j\omega})]$ represent amplitude and phase distortions, respectively. If $|T(e^{j\omega})|$ is constant for all $\omega$, then there is no amplitude distortion. Also, if $T(Z)$ is a linear phase FIR function, then $\arg[T(e^{j\omega})] = k\omega$, and there is no phase distortion. As a result, $T(Z)$ becomes a delay, i.e., $T(Z) = CZ^{-n_0}$, so that $\hat{x}(n)$, reconstructed signal, is a delayed version of $x(n)$, i.e., $\hat{x}(n) = cx(n - n_0)[7]$.

Smith and Barnwell[8] have shown first time that amplitude and phase distortions can be eliminated simultaneously by choosing

$$H_1(Z) = Z^{N-1}H_0(-Z^{-1})$$ (4.10)
where \((N - 1)\) is odd and \(N\) is the order of \(H_1(Z)\). Thus, we have

\[
T(Z) = \frac{1}{2} Z^{-(N-1)} [H_0(Z)H_0(Z^{-1}) - H_0(-Z)H_0(-Z^{-1})] = CZ^{-(N-1)}
\]  

(4.11)

Therefore, the perfect reconstruction requirement reduces to finding an \(H(Z) = H_0(Z)\) so that

\[
Q(Z) = H(Z)H(Z^{-1}) + H(-Z)H(-Z^{-1}) = C
\]

\[
= R(Z) + R(-Z)
\]  

(4.12)

The perfect reconstruction requirement in time is expressed as[5]

\[
\rho(2n) = \sum_{k=0}^{N-1} h(k)(k + 2n)
\]  

(4.13)

where \(\rho(2n)\) is the autocorrelation function.
Figure 4.7 The two-channel QMF bank.

In summary, we have the perfect reconstruction conditions for the 2 band PR-QMF banks as follows;

\[ F_0(Z) = -H_1(-Z) \]
\[ F_1(Z) = H_0(-Z) \]
\[ H_0(Z) = H(Z) \]

and

\[ R(Z) = H(Z)H(Z^{-1}) \iff \rho(n) = h(n) \ast h(-n) \]
\[ R(Z) + R(-Z) = 1 \iff \rho(2n) = \rho(n) \]

4.4 M-Band Tree Decomposition

Once a given signal \( x(t) \) is sampled at \( f_s \) and split into two subband signals, \( X_L(n) \) and \( X_H(n) \), each of these subband signals can be further decomposed into more than 2 subbands in the same manner as the initial signal \( x(n) \). Four subband signals, thus are obtained after reduction of the sampling rate to \( f_s/4 \). The spectrum of each of these subbands, \( X_{LL}(n) \), \( X_{LH}(n) \), \( X_{HL}(n) \) and \( X_{HH}(n) \), represents the subspectrum of \( x(n) \) in the corresponding subband. This decomposition-reconstruction structure can be repeated \( p \) times yielding a \( p \)-stage hierarchical tree decomposition. The initial
signal is thus decomposed into $M=2^p$ subbands. The subband tree decomposition technique is shown in Figure 4.8 for 4-band regular tree and in Figure 4.9 for 7-band dyadic tree decomposition[9].

### 4.5 Two Dimensional Separable Case

The two dimensional (2-D) filter bank is a direct extension of 1-D filter bank in separable filter case. In the separable case, the filters used can be expressed as the product of two one-dimensional filters as given in Eq.(4.16).

$$h(n_1,n_2) = h_1(n_1)h_2(n_2)$$  \hspace{1cm} (4.16)

The separability feature of the filter provides an alternative method of implementation of 2D-QMF banks. Figure 4.10 shows a four band analysis/synthesis filter bank structure. As shown, the structure consists of a set of one dimensional filters which operate separately along the rows and the columns of the input signal.
It can be shown that the use of such filters will result an alias-free reconstruction of
the input signal at the receiver side[10].

The decomposition of input signal can be extended for more than four
subbands, i.e., 7, 10, 13 etc., by repeating the process as explained in section
4.4.
Figure 4.9 7 band dyadic tree decomposition.
Figure 4.10 4 band regular tree decomposition and reconstruction of a 2-D signal $x(m,n)$. 
Figure 4.11 7 band dyadic tree decomposition and reconstruction of a 2-D signal $x(m,n)$ using 2-D separable filters
CHAPTER 5  
VECTOR QUANTIZATION IN SUBBANDS

5.1 Introduction

Many different coding techniques can be used for the encoding of the subband signals. In this study, vector quantization is used to independently encode the subband signals.

In this chapter, the concentration is given to vector quantization and its applications in subbands. Section 5.2 covers the general concept of vector quantization. In section 5.3, codebook design and the LGB algorithm[11] is covered. Section 5.4 deals with the vector quantization in subbands.

5.2 Vector Quantization

Vector quantization, also known as block quantization, is a direct extension of scalar quantization. The basic principle here is to map an N-dimensional input vector \( x \) onto another N-dimensional vector \( y \), i.e.,

\[
y = VQ(x)
\]

where \( VQ(.) \) is the vector quantization operator. Reconstruction vector, \( y_i \), takes its value from one of the finite set of vectors

\[
Y = \{y_i, \ i = 1, \ldots, L\}.
\]

The set \( Y \) is referred as the codebook containing the \( L \) code-vectors. For an \( L \)-length codebook the bits per code vector is given by

\[
R = \frac{1}{N} \log_2 L.
\]

The vector quantization procedure can be described as follows. First, the \( N \)-dimensional vector \( x \) is constructed from the input signal. Next, the best fitting code
Figure 5.1 Illustration of clusters and the vector quantization for two-dimensional space.

vector $y_i$ minimizing the distortion measure is searched in the codebook. This can be expressed as

$$VQ(x) = y_i, \iff d(x, y_i) \leq d(x, y_j) \quad j = 1, \ldots, L$$

(5.4)

where $d(x, y)$ represents the distortion measure or distance measure between the vectors $x$ and $y$. The vector quantization process is shown in Figure 5.1 where two-dimensional space is divided into cells. The shape of each cell is uniquely determined by the location of the code vectors and the distortion measure.

5.3 Codebook Design

A codebook of size $L$ divides the $N$-dimensional space into cells $\{C_i\}, i = 1, \ldots, L$ associating each cell $C_i$ a code vector $y_i$. The vector quantizer assigns the code vector $y_i$ to the vector $x$ if $x$ falls into $C_i$. The optimal quantizer is found by minimizing the distortion over all possible $L$-level quantizers. The overall average distortion of
A vector quantizer is defined as

\[ D = \sum_{i=1}^{L} P(x \in C_i) \int_{x \in C_i} d(x, y_i) p(x) \, dx \]  

where \( P(x \in C_i) \) is the probability that \( x \) lies inside \( C_i \) and, \( p(x) \) is the multi-dimensional probability density function (pdf) of \( x \). The integral is taken over all components of \( x \). However, in practice the pdf is usually unknown. In that case we use a training set, consisting of a large number of vectors \( V_n, n = 1, 2, \ldots, M \). The codebook is designed using an iterative algorithm known as the K-means algorithm. Since this algorithm was first proposed by Linde, Gray and Buzo it is called as the LGB algorithm.[11]

### 5.3.1 The LGB Algorithm

The basic steps of LGB algorithm is implemented as follows[11]:

- **1. Initialization:** Iteration index is set to \( m=0 \). An initial codebook size \( L \) with the codebook vectors \( y_i^0, i = 1, \ldots, M \) is chosen.

- **2. Clustering:** The training vectors \( V_n, i = 1, \ldots, M \) are classified into the clusters \( C_i \) by using the nearest neighbor rule.

- **3. Updating:** New codebook vector \( y_i^{m+1} \) is calculated for each cell \( C_i^m \) by calculating the centroid of the training vectors classified to that cell:

\[ y_i^{m+1} = cent(C_i^m) = \frac{1}{M_i} \sum_{V_n \in C_i} V_n, \quad i = i, \ldots, L_i \]  

where \( M_i \) is the number of training vectors classified to cell \( C_i \).

- **4. Stop:** New average distortion is calculated and if the distortion is below the predetermined threshold then the iteration is stopped. Otherwise iteration index is increased by 1 and the clustering operation is performed.
There are several ways to choose the initial codebook for the LGB algorithm. In our approach, we used splitting technique which works as follows. The initial codebook contains only one vector which is the centroid of all training sequence. The second codebook with codebook size \( L = 2 \) is created by adding and subtracting a perturbance (a splitting vector) to the initial codebook. After optimizing this codebook, the splitting technique is repeated for larger size codebooks, i.e., \( L = 4, 8, 16, \ldots, 512 \) etc. In our experiment \( L = 512 \) is found as the optimal codebook size with respect to overall distortion and, iteration is stopped.

5.4 Vector Quantization In Subbands

As explained earlier in section 5.3, the LGB algorithm is used in this study to generate the codebooks. First, the MCFD signal is decomposed into 7 band using dyadic tree structure. After studying the subband signals, some of the subbands are found insignificant and entirely discarded. The remaining subbands excluding LH band are adaptively vector quantized based on the motion vectors[13]. The LH band is statistically modeled and the model parameters are vector quantized.

The 2-D 7 band dyadic tree structure, given in Figure 4.11, is used in this study. The filter used is the 8-tap separable filter[14]. After discarding the insignificant bands, namely HLH, HL and HH bands, the remaining bands are treated as follows.

5.4.1 The Adaptive Vector Quantization Based on the Motion Vectors

In this study, we employed adaptive vector quantization based on the block motion vectors (MBAVQ) to quantize LLLL, LLLH and LHLH bands as suggested in Ref [13].

In our approach, the motion compensation is based on block matching algorithm using brute-force method. The block size is set to 8x8 and the maximum displacement in two directions, horizontally and vertically, is set to \( \pm 6 \) pixels.
Each 8x8 block in full frame resolution corresponds to a 4x4 block in 4 subbands. Since the LL band is further decomposed into 4 subbands as seen in Figure 5.2, each 4x4 block in LL band corresponds to a 2x2 block in these subbands. The 4x4 and 2x2 blocks correspond to a block motion vector of size 8x8 in full frame resolution. In his thesis, Mutlag stated that there is a relation between motion vector magnitude and the MCFD variance of the corresponding block[13]. In general, large magnitude motion vectors represent high variance blocks in the MCFD signal while blocks with small motion vectors have small variances. By using this relation the codebooks are created depending on the motion vector magnitude. The magnitude of motion vector $\hat{m}$ is given by

$$\hat{m} = \max(|i|, |j|)$$

(5.7)

where $i$ and $j$ are the horizontal and vertical displacements respectively. The block motion vectors are classified into 3 groups depending on their motion magnitudes:

- **Group 1**: $\hat{m}=1$ or 2
- **Group 2**: $\hat{m}=3$ or 4
• Group 3: \( \hat{m} = 5 \) or 6.

Codebooks are generated using the subblocks corresponding to these groups. As a result, 9 codebooks are generated for the LLLL, LLLH and LLHL bands using the LGB algorithm.

For the LLLL band, the codebook contains 512 vectors in which each vector is in dimension 4. For the LLLH and LLHL bands the codebook size is 512 and each codeword is in dimension 16. For the latter case, 4 motion vectors are averaged and these motion vectors are used to create the codebooks.

5.4.2 Vector Quantization for the AR(1) Model Parameters

As mentioned earlier, the LH band is AR(1) modeled and model parameters are vector quantized and encoded for transmission. The model parameters, \( p_h \), \( \rho_v \), \( \sigma^2 \), and \( \eta \), are vector quantized as follows: for means and variances two 256 length codebooks in which each codeword is in dimension 16 are generated. For the prediction coefficients, the codebook size is set to 512 where each codeword is also in dimension 16.

In conclusion, 12 codebooks are generated to vector quantize the subbands and model parameters.
The performance of the proposed low bit-rate hybrid subband codec was simulated. The first forty frames of monochrome video test sequences CINDY, MONO, DUO, QUARTET and TOPGUN are used. The video frames are 512x400 pixel size except 240x352 for TOPGUN sequence, and 8 bits/pixel.

Simulations are carried out in the following manner. First, the MCFD signals are split into 7 subbands using 2-D dyadic tree structure and separable 8-tap filters[14]. Next, the statistical modeling of some subband signals are studied. The last step, the quantization, is carried out after modeling those subbands.

6.1 Subband Decomposition of the MCFD Signals
In this study, 7 band 2-D dyadic tree structure is employed for decomposition of the MCFD signal. This analysis/synthesis subband tree structure is given in Figure 4.11. The filters employed are 8-tap separable filters. The frequency response of these filters are given in Figure 6.1. After studying the subband signals, LLHH, HL, HH bands are found insignificant and completely discarded.

6.2 Statistical Modeling In Subbands
The remaining subbands are studied for statistical modeling using 2-D AR(1) technique. The LH band is statistically modeled. The model parameters are quantized and sent to the receiver side for the reconstruction of LH band. The modeling procedure was explained in detail in Chapters 3 and 5.

Frame by frame variation of subband variances for LH band before and after 2-D AR(1) modeling of the test sequence "CINDY" was displayed in Figure 3.3. As
seen from the figure, modeling brings some error, but this error can be tolerated for the low bit-rate coding applications.

6.3 Quantization

Vector quantization is used to encode the subbands. The Motion Based Adaptive Vector Quantization (MBAVQ) is used for the subbands which are not modeled. Codebooks are generated using the LGB algorithm. For the statistically modeled LH band, the model parameters for each 4x4 blocks are quantized using the classical VQ algorithm. The more information about quantization was given in chapter 5.

The peak-to-peak signal to noise ratio is used as the objective performance criterion and defined as

\[ SNR_{pp}(dB) = 10 \log_{10} \left( \frac{255^2}{\frac{1}{E\{(X(i,j)-X(i,j))^2\}}} \right) \]  \hspace{1cm} (6.1)
Frame by frame variation of the average $SNR_{pp}$ values in dB for the test sequence "CINDY".

where the denominator term is the mean square coding error.

Frame by frame variation of peak-to peak SNR values before and after quantization for the test sequence "CINDY" is given in Figure 6.2 along with the average $SNR_{pp}(dB)$ values for the first forty frames. Figure 6.2 also shows the $SNR_{pp}(dB)$ values for the 10 band case which is used for comparison.

The total bit-rate for the proposed hybrid video codec can be expressed as

$$B = B_M + B_{SB} + B_{AR(1)}$$

where

- $B_M =$ average bits/pixel for motion information.
- $B_{SB} =$ average bits/pixel for the subband signals which are not modeled.
- $B_{AR(1)} =$ average bits/pixel for the AR(1) modeled subbands.
The measure of information is expressed by the entropy. The first order entropy is defined as

\[ H = - \sum_{i} p(i) \log_2 p(i) \]  

(6.3)

where \( p(i) \) is the probability of the source symbol \( i \). The frame by frame variation of entropy values for the first forty frames of test sequence "CINDY" is given in Figure 6.3 along with the average entropy values.

The performance of the proposed algorithm was also tested for the video sequences which are not a part of the training sequence. "TOPGUN" which is not a part of training sequence, gave the superior SNR results for the proposed algorithm compared to the other algorithms used for comparison. Figures 6.4 and 6.5 display the \( SNR_{pp}(dB) \) and entropy values of the tested 100 frames of the video sequence "TOPGUN". These figures also show the performance of the algorithms used for comparison.

25th and 26th frames of the test sequence "CINDY" are given in Figures 6.6 - 6.10 along with the MCFD frames for coded and original cases.
Figure 6.3 Frame by frame variation of the first order entropy values for the test sequence "CINDY".
Figure 6.4 Frame by frame variation of the average $SNR_{pp}$ values in dB for the test sequence "TOPGUN".
Figure 6.5 Frame by frame variation of the first order entropy values for the test sequence "TOPGUN".
Figure 6.6 25th frame of the test sequence "CINDY"
Figure 6.7 The direct difference between the frames 25 and 26 of test sequence "CINDY"
Figure 6.8 26th frames of the test sequence "CINDY", the original (top) and coded (bottom) \( SNR_{pp} = 34.1, bpp = 0.24 \)
Figure 6.9 26th MCFD frames of "CINDY", the original (top) and coded (bottom) ($SNR_{pp} = 34.1$, $bpp = 0.24$).
Figure 6.10 LH band of the 26th MCFD frames of "CINDY", the original (top) and statistically modeled (bottom).
A hybrid low bit-rate video codec is proposed in this study. The proposed technique achieves a good objective and visual performance at the low bit-rates $B \leq 0.30$ bits/pixel with the $SNR_{pp}$ 30-36 dB range.

It is well known that the training sequence dependency of vector quantization is a very important problem. Furthermore, the modeling approach used introduces some error due to stationarity assumption. In spite of these drawbacks, the statistical modeling is a viable approach for the low-correlated MCFD signal subbands and, the study to improve and develop better modeling techniques is an open field. In conclusion, the future work is to find better modeling approaches to have better performance and visual quality for low bit-rate video coding applications.
APPENDIX A

Simulation Program for the 7 Band Dyadic Tree Structure

c source code for the proposed adaptive subband video coding with
motion compensation using MBAVQ

c nx row size of the picture
c ny column size of the picture

c frame1 previous frame

c frame2 current frame

c pics search frame from the previous frame

c recon prediction of the current frame with motion compensation

c ibs block size (8 is used)
c ip assumed maximum displacement (Max of 6)
c frm2msk ibs*ibs size mask of the current frame to be
  motion compensated

c frm1msk ibs*ibs size mask of the previous frame in the
  same geometrical position (used for motion detection)
c err1 motion compensated frame difference signal

c searg search region (ibs+ip)*(ibs+ip)
c mask same as frm2msk

parameter(nx=400,ny=512)
  integer motionv(50,64),ifld
  common /motionv/ motionv
  common /ifld/ ifld
  common /ifl/ ifl
  real outimg(400,512)

  real frame1(nx,ny),frame2(nx,ny),pics(416,528)
  real recon2(nx,ny),frm1msk(8,8),frm2msk(8,8),err1(nx,ny)
  real recon3(400,512), errtemp(400,512)
  integer ifrm1(nx,ny),ifrm2(nx,ny)
  real dirdif(400,512)

  real b1v1(512,4),b1v2(512,4),b1v3(512,4)
  real b2v1(512,16),b2v2(512,16),b2v3(512,16)
  real b3v1(512,16),b3v2(512,16),b3v3(512,16)
  real b4v1(256,16),b4v2(256,16),b4v3(512,16),b4v4(512,16)

  common /entropy1/entropy1
  common /entropy2/entropy2
common /entropy3/entropy3
common/arbitrate/arbitrate
common /vqcodebook1/ b1v1, b1v2, b1v3
common /vqcodebook2/ b2v1, b2v2, b2v3
common /vqcodebook3/ b3v1, b3v2, b3v3
common /vqcodebook4/ b4v1, b4v2, b4v3, b4v4

character*1 pim(nx, ny)
character*1 pim1(nx, ny)
integer mcvector(50, 64)

common /AAA/ searg(24, 24), mask(8, 8)

print*, ’READING CODEBOOKS’

open (15, file= ’B1NEW/b1v1.12’)
do 10 i=1, 512
read(15, *) (b1v1(i, j), j=1, 4)
10 continue
close(15)

close(15)

open (16, file= ’B1NEW/b1v2.34’)
do 11 i=1, 512
read(16, *) (b1v2(i, j), j=1, 4)
11 continue
close(16)

close(16)

open (17, file= ’B1NEW/b1v3.56’)
do 12 i=1, 512
read(17, *) (b1v3(i, j), j=1, 4)
12 continue
close(17)

close(17)

open (20, file= ’QUANTIZER/b2v1.12’)
do 1110 i=1, 512
read(20, *) (b2v1(i, j), j=1, 16)
1110 continue
close(20)

close(20)

open (21, file= ’QUANTIZER/b2v2.34’)
do 1111 i=1, 512
read(21, *) (b2v2(i, j), j=1, 16)
continue
close(21)

open (22,file='QUANTIZER/b2v3.56')
do 1112 i=1,512
   read(22,*) (b2v3(i,j),j=1,16)
continue
close(22)

open (23,file='QUANTIZER/b3v1.12')
do 1113 i=1,512
   read(23,*) (b3v1(i,j),j=1,16)
continue
close(23)

open (24,file='QUANTIZER/b3v2.34')
do 1114 i=1,512
   read(24,*) (b3v2(i,j),j=1,16)
continue
close(24)

open (25,file='QUANTIZER/b3v3.56')
do 1115 i=1,512
   read(25,*) (b3v3(i,j),j=1,16)
continue
close(25)

open (26,file='QUANTIZER/b4v4.mn')
do 1116 i=1,256
   read(26,*) (b4v1(i,j),j=1,16)
continue
close(26)

open (27,file='QUANTIZER/b4v4.var')
do 1117 i=1,256
   read(27,*) (b4v2(i,j),j=1,16)
continue
close(27)

open (28,file='QUANTIZER/b4v4.rh')
do 1118 i=1,512
   read(28,*) (b4v3(i,j),j=1,16)
continue
close(28)
open (29, file='QUANTIZER/b4v4.rv')
do 1119 i=1,512
   read(29,*) (b4v4(i,j), j=1,16)
1119    continue
close(29)
print*, 'CODEBOOKS ARE READ'
c  mfld: final field to be read
 c  ifld: starting field number
    mfld = 34
    ifld = 33

    call read_frm(ifld, pim)
    if1 = 0
  c********************************************************************
  c  Frame One is read into frame1 array
  c*********************************************************************
do 100 i=1,nx
   do 100 j=1,ny
      ifrml(i,j)=ichar(pim(i,j))
      if(ifrml(i,j).lt.0) ifrml(i,j)=256+ifrml(i,j)
      frame1(i,j)=float(ifrml(i,j))
100    continue

c  call write_in_frm(ifld, frame1)
c  call write_out_frm(ifld, frame1)

write(35,*) 'Original Image'
c  The loop to process mfld number
 c  of frames begins here
6000  ifld = ifld+1
    ifl = ifl+1
    write(*,*) 'Frame Number = ', ifld, ifl
    write(35,*) 'Frame Number = ', ifld

call read_frm(ifld, pim1)
c********************************************************************
c  Current frame is read into frame2
  c********************************************************************
do 110 i=1,nx
  do 110 j=1,ny
    ifrm2(i,j)=ichar(pim1(i,j))
    if(ifrm2(i,j).lt.0) ifrm2(i,j)=256+ifrm2(i,j)
  frame2(i,j)=float(ifrm2(i,j))
  110 continue

  call write_in_frm(ifld,frame2)

******************************************************************************
  c Auto-Correlation, Mean, Variance are calculated in the subroutine autocor
******************************************************************************
  c  print *,'Frame k'
    write(35,*) 'Frame k'
    call autocor(frame1,nx,ny)
  c  print *,'Frame k+1'
    write(35,*) 'Frame K+1'
    call autocor(frame2,nx,ny)
  do 2000 i=1,400
    do 2000 j=1,512
      dirdif(i,j)=frame2(i,j)-frame1(i,j)
  2000 continue
  c  write(35,*) 'Direct Difference Frame'
    call autocor2(dirdif,nx,ny)

  c ip: displacement
    ip=6
  c  ibs: the mask block size
    ibs=8
  c  imthd: Enter 1 for Brute-force method and 2 for Orthogonal src
    imthd=1
  c  imdetect: Enter 1 if motion-detection is required'
    imdetect=1
c**************************************************************
c Search Array pics is Initialized
c**************************************************************
do 101 i=1,nx+2*ip
do 101 j=1,ny+2*ip
   pics(i,j)=0.0
101 continue
c**************************************************************
c Search Array is generated from the previous frame.
c Borders are filled with first(or last) ip
c rows(or clums) of the previous frame
c**************************************************************
do 155 i=1,nx
do 155 j=1,ny
   pics(i+ip,j+ip)=framel(i,j)
155 continue
do 111 i=1,ip
do 111 j=1,ny
   pics(i,j)=frame1(i,j)
   pics(i+nx+ip,j)=framel(i+nx-ip,j)
111 continue
do 112 i=1,nx
do 112 j=1,ip
   pics(i,j)=frame1(i,j)
   pics(i,j+ny+ip)=framel(i,j+ny-ip)
112 continue
c**************************************************************
c Prediction of the Current frame is Initialized
c**************************************************************
do 240 i4=1,nx
do 240 j4=1,ny
   recon2(i4,j4)=0.0
240 continue
c**************************************************************
c The current frame is divided into 8*8 blocks and
c motion compensated. mcount keeps count of number
c of moving blocks.
c**************************************************************
mcount=0
  do 200 i=1,nx/ibs
    do 200 j=1,ny/ibs
      iact=(i-1)*ibs+1
      jact=(j-1)*ibs+1
    if (imdetect .eq. 1) then
      do 401 k=1,ibs
        do 401 l=1,ibs
          frmlmsk(k,l)=framel(iact-l+k,jact-1+1)
          frm2msk(k,l)=frame2(iact-1+k,jact-1+1)
        401 continue
      c********************************************************
      c     First the motion is detected
      c********************************************************
      call motiondetect(frm1msk,frm2msk,ibs,indx)
      if (indx .eq. 1) then
        mcount=mcount+1
        do 410 i1=1,ibs+ip*2
          do 410 j1=1,ibs+ip*2
            searg(i1,j1)=pics(i1+iact-l+ip-ip,j1+jact-l+ip-ip)
        410 continue
      do 420 i2=1,ibs
        do 420 j2=1,ibs
          mask(i2,j2)=frame2(iact-1+i2,jact-1+j2)
        420 continue
      ****************************************************
      if motion is detected, it is estimated and predicted
      ****************************************************
      call matct(ip,ibs,imthd,n,nn,Num)
      motionv(i,j)=max(abs(n-7),abs(nn-7))
      mcvector(i,j)=Num
      do 430 i3=1,ibs
        do 430 j3=1,ibs
          recon2(iact-1+i3,jact-1+j3)=pics(iact+ip-1+(n-ip)-1+i3,
              + jact+ip-1+(nn-ip)-1+j3)
        430 continue
      else
        motionv(i,j)=0
mcvector(i,j)=0  
      write(55,*) mcvector(i,j)  
do 402 k1=1,ibs  
do 402 l1=1,ibs  
recon2(iact-1+k1,jact-1+l1)=frame1(iact-1+k1,jact-1+l1)  
402 continue  
endif  
else  
   do 210 i1=1,ibs+ip*2  
do 210 j1=1,ibs+ip*2  
      searg(i1,j1)=pics(i1+iact-1+ip-ip,j1+jact-1+ip-ip)  
210 continue  
   do 220 i2=1,ibs  
do 220 j2=1,ibs  
      mask(i2,j2)=frame2(iact-1+i2,jact-1+j2)  
220 continue  
call matct(ip,ibs,imthd,n,nn,Num)  
do 230 i3=1,ibs  
do 230 j3=1,ibs  
recon2(iact-1+i3,jact-1+j3)=pics(iact+ip-1+(n-ip)-1+i3,  
+ jact+ip-1+(nn-ip)-1+j3)  
230 continue  
endif  
c      write(55,* ) motionv(i,j)  
200 continue  

*******************************  
MCFD signal is generated  
c*******************************  
do 650 i=1,400  
do 650 j=1,512  
650    recon3(i,j)=0.0  
do 700 i=1,400  
do 700 j=1,512
recon3(i,j)=recon2(i,j)

\begin{verbatim}
700       do 599 i=2,nx-1
    do 600 j=2,ny-1
        recon3(i,j)=(1.0/16.0)*(recon2(i-1,j-1)+2.0*recon2(i - 1,j) + recon2(i-1,j+1)+2.0*recon2(i,j-1)+4.0*recon2(i,j) +2.0*recon2(i,j+1)+recon2(i+1,j-1)+2.0*recon2(i+1,j) +recon2(i+1,j+1))

600       continue

599       continue
\end{verbatim}

\begin{verbatim}
700       do 300 i=1,nx
    do 300 j=1,ny
        err=(err+abs(frame2(i,j)-recon3(i,j)))
        errl(i,j)=frame2(i,j)-recon3(i,j)

300       continue

print *, 'the value of err=', err
write(35,*) 'the value of err=', err

if (imdetect .eq. 1) then
    print *, 'Number of blocks motion detected = ', mcount
    write(35,*) 'Number of blocks motion detected = ', mcount
endif

print *, 'Error Signal'
write(35,*) 'Error Signal'
call autocor(errl,nx,ny)
print *, 'Predicted signal'
write(35,*) 'Predicted signal'
call autocor(recon2,nx,ny)

    do 350 i = 1,nx
    do 350 j = 1,ny
        errtemp(i,j) = errl(i,j)
        outimg(i,j)=0.0

350       continue

call bitrates2(mcvector,entropy,50,64)
call writeimgs(err1,400,512,'diff25')

*****CODING OF MCFD SIGNAL IS CARRIED OUT HERE*****

**********7-BAND FILTER BANK IS CALLED**********
call subband(err1,outimg,400,512)
print *, 'Error Signal after the vector quantization'
write(35,*) 'Error Signal after the vector quantization'
call autocorl(outimg,nx,ny)
vecmean = 0.0
vecvar = 0.0
do 351 i = 1,nx
do 351 j = 1,ny
vecmean = vecmean + (errtemp(i,j) - outimg(i,j))
vecvar = vecvar + (errtemp(i,j) - outimg(i,j))**2
continue
vecmean = vecmean/(nx*ny)
vecvar = vecvar/(nx*ny) - vecmean**2
write(35,*) 'Variance of quantization error',vecvar

**********************************************************
Quantized MCFD signal is added to the motion compensated
prediction of the current frame and put into frame1 and
this becomes the previous frame for the next current frame
**********************************************************
xmse = 0.0
do 1000 i=1,nx
do 1000 j=1,ny
frame1(i,j)=recon3(i,j)+outimg(i,j)
xmse = xmse + (frame2(i,j)-frame1(i,j))**2
continue

call write_out_fr(frame1)
call write_out_frm(ifld,frame1)
xmse = xmse/(nx*ny)
SNR = 10*log10(255**2/xmse)
write(*,*) 'SNR = ',SNR
write(35,*) 'SNR = ',SNR
write(100,*) ifld ,SNR

write(*,*) 'Mean Square Error after Vector
+ Quantization=',xmse
write(36,*) ifld,xmse
write(*,*) 'mean square error=',xmse
tbit1111=entropy1/(400*512)
tbit11lh=entropy2/(400*512)
tbit11hl=entropy3/(400*512)
tbitlh=arbitrate/(400*512)

xmbitrate = entropy/64.0

tbitsub = (entropy1+entropy2+entropy3+arbitrate)/(400*512)
t bitrate = xmbitrate+tbitsub

write(200,*) xmbitrate

write(201,*) tbitsub
write(35,*) 'total bitrate=',t bitrate
write(202,*) t bitrate
write(*,*) 'total bitrate=',t bitrate

*********************************************************************************/
*if all the frames are not processed go back
*********************************************************************************/

if(ifld.lt.mfld) go to 6000
stop
end

***************
* subroutine matct
***************

subroutine matct(ip,ibs,imthd,n,nn,Num)
common /AAA/ searg(24,24),mask(8,8)
real test(13,13)
do 50 i=1,2*ip+1
    do 50 j=1,2*ip+1
        test(i,j)=0.0
        do 50 ii=1,ibs
            do 50 jj=1,ibs
                test(i,j)=abs(mask(ii,jj)-searg(i+ii-1,j+jj-1))+test(i,j)
        50 continue
60

mixed force technique
if (imthd .eq. 1 ) then
  tmin=1.0e20
  do 100 i=1,2*ip+1
    do 100 k=1,2*ip+1
      if(test(i,k) .lt. tmin) then
        tmin=test(i,k)
        n=i
        nn=k
      endif
  100 continue
else
  call ortho(test,ip,ibs,icent,jcent)

  n=icent
  nn=jcent
endif

  c
  c Generates a number between 1 & 169, The number indicates
  c the motion information
  c
  Num=(n-1)*(ip*2+1)+nn
  c
  write(*,*) Num,n,nn
  return
end

subroutine ortho(test,ip,ibs,icent,jcent)
  ********************************************
  * Independent Orthognal Search Technique *
  ********************************************
real test(ip*2+1,ip*2+1)
icent=ip+1
jcent=ip+1
l=ip/2.+ .5
istep=0
if ((test(icent,jcent) .lt. test(icent,jcent-1)) .and.
  + (test(icent,jcent) .lt. test(icent,jcent+1))) then
  icent=icent
  jcent=jcent
else if ((test(icent,jcent-1) .lt. test(icent,jcent)) .and.
  + (test(icent,jcent-1) .lt. test(icent,jcent+1))) then
  icent=icent
  jcent=jcent-1
else if ((test(icent,jcent+1) .lt. test(icent,jcent)) .and.
  + (test(icent,jcent+1) .lt. test(icent,jcent-1))) then
  icent=icent
  jcent=jcent+1
endif

istep=istep+1

if ((test(icent,jcent) .lt. test(icent-1,jcent)) .and.
  + (test(icent,jcent) .lt. test(icent+l,jcent))) then
  icent=icent
  jcent=jcent
else if ((test(icent-1,jcent) .lt. test(icent,jcent)) .and.
  + (test(icent-1,jcent) .lt. test(icent+l,jcent))) then
  icent=icent-1
  jcent=jcent
else if ((test(icent+1,jcent) .lt. test(icent,jcent)) .and.
  + (test(icent+1,jcent) .lt. test(icent-1,jcent))) then
  icent=icent+1
  jcent=jcent
endif

istep=istep+1

if (l .ne. 1) then
  l=(1/2.0+.5)
go to 10
  endif
return
end

subroutine motiondetect(frmlmsk,frm2msk,ibs,indx)
**Subroutine calculates if motion is present in the (ibs*ibs) subblock**

```fortran
real frmlmsk(ibs,ibs), frm2msk(ibs,ibs)

kount = 0
do 10 i = 1, ibs
   do 10 j = 1, ibs
      thrsh = abs(frm1msk(i,j) - frm2msk(i,j))
      if (thrsh .gt. 3) kount = kount + 1  
      10 continue
if (kount .gt. 10) then
   indx = 1
else
   indx = 0
endif
print *, 'index', indx
return
end
```

**This Subroutine calculates the prediction coefficients, means and variances of each ibx*iby block and forms the AR(1) model of corresponding subband frame**

```fortran
subroutine arl(fror,nx,ny,armod,ibx,iby)
character*1 pimm(200*256)
real fror(1:nx,1:ny)
real autoc(12800)
real autoc1(12800)
real uframe1(-12:212,-12:268)
real rmean1(3200), fror0(-10:210,-10:266)
real framar1(1:200,1:256)
real rh(3200), rv(3200), var(3200)
real armod(1:200,1:256)
real fror(-5:205,-5:261)
real mean,sigma
integer hist41(512)
integer hist42(512)
integer hist43(512)
integer hist44(512)
common/arbitrate/arbitrate
```
real yy(1:16)
common /yy/yy

do 13 i=-5 ,205
do 13 j=-5 ,261
  from1(i,j)=0.0
continue

do 44 i=1,3200
  rmean1(i)=0.0
  rh(i)=0.0
  rv(i)=0.0
  var(i)=0.0
continue

write(1,*)((from(i,j),j=1,256),i=1,200)

do 39 i=1,200
  do 39 j=1,256
    from1(i,j)=from(i,j)
    framar1(i,j)=0.0
    armod(i,j)=0.0
continue

**********************************************
* IN FOLLOWING LOOP ZERO MEAN FRAME OPTAINED*
**********************************************

kk=0
  do 10 i=0,nx-ibx,ibx
  do 11 j=0,ny-iby,iby
    ii=i
    jj=j
    kk=kk+1
    rmn=0.0
    do 12 k=ii+1,ii+ibx
      do 12 l(jj+1,jj+iby)
        rmn=rmn+from1(k,l)
      continue
    rmean1(kk)=rmn/(ibx*iby)
    do 14 m=ii+1,ii+ibx
    do 14 n(jj+1,jj+iby
\[
fror0(m,n) = fror1(m,n) - rmean1(kk)
\]

14  continue

11  continue

10  continue

\[
do 50 m = -12, nx + 12
\\do 50 n = -12, ny + 12
\\uframe1(m,n) = 0.0
\]

50  continue

mm = 0

******************************************************************************
* IN FOLLOWING LOOP, ZERO MEAN MCFD FRAME MODELED BY *
* USING THE AR1 MODEL PARAMETERS. FIRST, VARIANCE, *
* AUTOCORRELATION, \( \text{RH}, \text{RV} \), OF EACH \( \text{ibx} \times \text{iby} \) BLOCKS ARE *
* CALCULATED *
******************************************************************************

do 511 i = 0, nx - ibx, ibx
\do 512 j = 0, ny - iby, iby
ii = i
jj = j
mm = mm + 1
rautoc = 0.0
\do 71 k = ii + 1, ii + ibx
autoc(k) = 0.0
\do 72 l = jj + 1, jj + iby - 1
autoc(k) = autoc(k) + fror0(k, l)*fror0(k, l + 1)
72  continue
rautoc = rautoc + autoc(k)
71  continue

rautoc = rautoc / (ibx*iby)

rautoc1 = 0.0
\do 23 l = jj + 1, jj + iby
autoc1(l) = 0.0
\do 24 k = ii + 1, ii + ibx - 1
autoc1(l) = autoc1(l) + fror0(k, l)*fror0(k + 1, l)
24  continue
rautoc1 = rautoc1 + autoc1(l)
23  continue
rautoc1 = rautoc1/(ibx*iby)

var1=0.0
do 25 k=ii+1, ii+ibx
   do 26 l=jj+1, jj+iby
      var1=var1+fror0(k,1)*fror0(k,l)
   26 continue
25 continue

var(mm) = var1/(ibx*iby)
rh(mm) = rautoc/var(mm)
rv(mm)= rautoc1/var(mm)
c      write(50,*) rh(mm),rv(mm)

512 continue
511 continue

****************************************************************************
* QUANTIZATION OF THE AR1 MODEL PARAMETERS*
* ARE CARIED OUT HERE
**************************************************************************

print*, 'quantizing ar1 parameters'
call vec_quant4(rmean1,1,hist41,256)
call vbitrates4(hist41,bs1,256)
call vec_quant4(var,2,hist42,256)
call vbitrates4(hist42,bs2,256)
call vec_quant4(rh,3,hist43,512)
call vbitrates4(hist43,bs3,512)
call vec_quant4(rv,4,hist44,512)
call vbitrates4(hist44,bs4,512)

arbitrate=bs1+bs2+bs3+bs4
write(*,*) 'BITRATE FOR AR1=', arbitrate

write(100,*) (hist41(i),i=1,512)

N=16
sigma=1.0
mean=0.0
nu=0
call gauss(N,mean,sigma,iseed)

do 518 i=0, nx-ibx,ibx
  do 518 j=0, ny-iby,iby
    ii=i
    jj=j
    nu=nu+1
    varno=(1.0-rh(nu)**2)*(1.0-rv(nu)**2)*var(nu)
    sigma1=sqrt(varno)
  
nn=0
  do 27 k=ii+1, ii+ibx
    do 28 l=jj+1, jj+iby
      nn=nn+1
      uframel(k,l)=rh(nu)*uframe1(k,l-1)+rv(nu)*uframel(k-1,1/l-1)+
                      sigma1*yy(nn)
  28  continue
  27  continue

*************************************************
*MEANS ARE ADDED TO THE AR1 MODELED MCFD FRAME*
*************************************************

do 29 k=ii+1, ii+ibx
  do 30 l=jj+1, jj+iby
    framarl(k,1)=uframe1(k,l)+rmeanl(nu)
    uframel(k,l)=0.0
  30  continue
  29  continue

518  continue

do 510 i=1,nx
  do 510 j=1,ny
    armod(i,j)=framar1(i,j)
  510  continue

c  open(99,file='ard25',access='direct',form='unformatted'
  ,recl=nx*ny)
c  do 690 i=1,nx
  do 691 j=1,ny
    ip=int(armod(i,j))+128
    if(ip.gt.255) ip=255
c if (ip.lt.0) ip=0
if(ip.gt.128) ip=ip-255
kk=j+(i-1)*ny
pimm(kk)=char(ip)
c691 continue
continue
c write(99,rec=1) (pimm(j),j=1,nx*ny)
c close(99)
write(*,*) 'OKAY'
return
end

**********************************************************************
* GAUSSIAN NOISE GENERATOR *
**********************************************************************
subroutine gauss(N,mean,sigma,iseed)
real x(1:16),mean,yy(1:16)
common /yy/yy
do 1 i=1,N
x(i)=gran(mean,sigma,iseed)
yy(i)=x(i)
1 continue
return
end

****************************************
function gran(mean,sigma,iseed)
real mean
u=0
do 1 i=1,12
u=u+ran(iseed)
1 continue
gran=sigma*(u-6)+mean
return
end

************************************************************************
subroutine write_out_fr(frm)
real frm(400,512)
real frml(1:512,1:512)
character*1 image(512*512)
common /ifl/ ifl
parameter(nx=400,ny=512)
open(21,file='fr25',access='direct',form= & 'unformatted',recl=512*512)
do 300 i=0,513
  do 300 j=0,513
    300    frml(i,j)=0.0
  end do
  end do

  do 200 i=1,400
    do 200 j=1,512
      frm1(i,j)=frm(i,j)
    200      continue
  end do

  do 599 i=1,nx
    do 600 j=1,ny
      frml(i,j)=(1.0/16.0)*(frm(i-1,j-1)+2.0*frm(i-1,j)+
                       2.0*frm(i-1,j+1)+2.0*frm(i,j-1)+4.0*frm(i,j)+
                       2.0*frm(i,j+1)+frm(i+1,j-1)+2.0*frm(i+1,j)+
                       frm(i+1,j+1))
    600  continue
  599  continue

  do 499 i=3,nx-2
    do 500 j=3,ny-2
      frml(i,j) =
        (1.0/256.0)*((frm(i-2,j-2)+frm(i-2,j+2)+
                      frm(i-1,j-1)+frm(i-1,j+1)+
                      4.0*(frm(i-2,j-1)+frm(i-2,j+1)+
                           frm(i-1,j-2)+frm(i-1,j+2))+
                      4.0*(frm(i+1,j-2)+frm(i+1,j+2)+
                           frm(i+2,j-1)+frm(i+2,j+1))+
                      6.0*(frm(i-2,j)+frm(i,j-2)+frm(i,j+2)+
                           frm(i+2,j))+
                      16.0*(frm(i-1,j-1)+frm(i-1,j+1)+
                             frm(i+1,j-1)+frm(i+1,j+1)))+
                      24.0*frm(i-1,j)+frm(i-1,j-1)+frm(i-1,j+1)+
                      36.0*frm(i,j)+(1./256.)*frm(i+2,j-2)
    500  continue
  499  continue

  do 10 i=1,512
    do 10 j=1,512
      ip=int(frm1(i,j)+.5)
      if(ip.gt.255) ip=255
      if(ip.lt.0) ip=0
      if(ip.gt.127) ip=ip-256
      image((i-1)*512+j) = char(ip)
  10  continue
write(21, rec=ifl)(image(j), j=1, 512*512)

close(21)

return

end

*****************************************************************************

subroutine write_out_frm(ifld, frm)
real frm(400, 512)
real pic1(1:512, 1:512)
character*1 image(512*512)

open(21, file='cindy.out', access='direct', form=
  & 'unformatted', recl=512*512)
do 300 i=0, 513
  do 300 j=0, 513
    pic1(i, j)=0.0
  300

do 200 i=1, 1400
  do 200 j=1, 1512
    pic1(i, j)=frm(i, j)
  200  continue

do 599 i=1, nx
  do 600 j=1, ny
    pic1(i, j)=(1.0/16.0)*(frm(i-1, j-1)+2.0*frm(i, j-1)+
      #+2.0*frm(i, j+1)+frm(i+1, j-1)+2.0*frm(i+1, j)+
      #+2.0*frm(i+1, j+1)
      +(1.0/16.0)*(frm(i-1, j)+2.0*frm(i, j)+
      #+2.0*frm(i, j+1)+frm(i+1, j)+2.0*frm(i+1, j+1))
  600  continue
  599 continue

do 10 i=1, 1400
  do 10 j=1, 1512
    ip=int(pic1(i, j)+.5)
    if(ip.gt.255) ip=255
    if(ip.lt.0) ip=0
    if(ip.gt.127) ip=ip-256
  10 continue
image((i-1)*512+j) = char(ip)
continue
write(21,rec=ifld)(image(j),j=1,512*512)
close(21)
return
dend

********************
* SUBROUTINE AUTOCOR*
********************

subroutine autocor(frame,nx,ny)
real frame(nx,ny)
real autoc(400),autoc1(512)
rautoc=0.0
do 11 k=1,nx
   autoc(k)=0.0
   do 12 l=1,ny-1
      autoc(k)=autoc(k)+frame(k,l)*frame(k,l+1)
   12 continue
   rautoc=rautoc+autoc(k)/ny
11 continue
rautoc1=0.0
do 13 l=1,ny
   autoc1(l)=0.0
   do 14 k=1,nx-1
      autoc1(l)=autoc1(l)+frame(k,1)*frame(k+1,l)
   14 continue
   rautoc1=rautoc1+autoc1(l)/nx
13 continue
rac=0.0
rmean=0.0
do 23 l=1,ny
   do 24 k=1,nx
      rac=rac+frame(k,l)*frame(k,l)
      rmean=rmean+frame(k,l)
   24 continue
23 continue
rmean=rmean/(nx*ny)
var=rac/(nx*ny)-rmean*rmean
rautoc=rautoc/nx-rmean*rmean
rautoc1=rautoc1/ny-rmean*rmean

write(35,*) 'Mean Variance'
write(35,*) rmean,var

rh=rautoc/var
rv=rautoc1/var

write(35,*) 'Autocor-H, Autocor-V'
write(35,*) rh,rv

return
end

*******************************************************************************
* subroutine initial             *
* This subprogram initialize the main program*                            
*******************************************************************************
subroutine initial
character*80 input_file
common /ina/ input_file

write (*,1)
write (*,3)
read (5,4) input_file

1    format (   )
3    format (' Enter the name of the file contains 
& ',/,'the order of the filters there coefficients, 
& input Image, and output file:')
4    format( a80)

return
end

c******************************************************************************
subroutine writeimgs(pic,nx,ny,name)
real pic(nx,ny)
character*1 pim(400*512)
character*20 name
open(1, file=name, access='direct',
+ form='unformatted', recl=400*512)
do 20 i=1, nx
  do 20 j=1, ny
    ip=int(pic(i,j))+128
    if(ip.gt.255) ip=255
    if(ip.lt.0) ip=0
    if(ip.gt.128) ip=ip-256
    mm=j+(i-1)*ny
    pim(mm)= char(ip)
  20 continue
write(1, rec=1) (pim(j), j=1, nx*ny)
close (1)
return
end

c******************************************
subroutine writeimg(pic, nx, ny, name)
  real pic(nx, ny)
  character*1 pim(400*512)
  character*20 name

  open(1, file=name, access='direct',
+ form='unformatted', recl=nx*ny)
do 20 i=1, nx
  do 20 j=1, ny
    ip=int(pic(i,j))
    if(ip.gt.128) ip=ip-256
    mm=j+(i-1)*ny
    pim(mm)= char(ip)
  20 continue
write(1, rec=1) (pim(j), j=1, nx*ny)
close (1)
return
end

c*********************************************
subroutine writeint(c, nx, ny, name)
  real c(nx, ny)
  character*20 name

  open(1, file=name)
do 10 i=1,nx
  write(1,*) (c(i,j),j=1,ny)
10  continue

close (1)
return
end

********************************************************************************
subroutine writeint1(pic,nx,ny,name)
integer pic(nx,ny)
character*20 name

open(1,file=name)

do 10 i=1,nx
  write(1,*) (pic(i,j),j=1,ny)
10  continue

close (1)
return
end

********************************************************************************
subroutine read_frm(ifld,pic)
character*1 pic(400,512)

open(1,file='/images/cindy',access='direct',form=
 & 'unformatted',recl=512)

icod1 = (ifld-1)*400
icod2 = (ifld-1)*400 + 200

do 10 i=1,200
  read(1,rec=icod1+i)(pic(2*i-1,j),j=1,512)
read(1,rec=icod2+i)(pic(i*2,j),j=1,512)
10 continue
close(1)
return
dend

******************************************************************************

subroutine write_in_fim(ifld,pic)
   real pic(400,512)
   character*1 image(512*512)

   open(22,file='cindy.in',access='direct',form=
     & 'unformatted',recl=512*512)

   do 10 i=1,400
      do 10 j=1,512
         ip=int(pic(i,j)+.5)
         if(ip.gt.255) ip=255
         if(ip.lt.0) ip=0
         if(ip.gt.127) ip=ip-256
         image((i-1)*512+j) = char(ip)
      10 continue

   do 20 i=204801,262144
      image(i) = char(003)
   20 continue

   write(22,rec=ifld)(image(j),j=1,512*512)

close(22)
return
dend

******************************************************************************

subroutine write_lfrm(pic,name)
   real pic(400,512)
   character*1 image(512*400)
   character*20 name
open(22, file=name, access='direct', form= & 'unformatted', recl=512*400)
do 10 i=1,400
do 10 j=1,512
   ip=int(pic(i,j)+.5)
   if(ip.gt.255) ip=255
   if(ip.lt.0) ip=0
   if(ip.gt.127) ip=ip-256
   image((i-1)*512+j) = char(ip)
10 continue

c    write(22, rec=1)(image(j), j=1, 512*400)
close(22)
return
end

***********************************************************************
* SUBROUTINE SUBBAND-7 BAND ANALYSIS AND SYNTHESIS*
***********************************************************************
* LL-LH-HL-HH Bands used       *
* Synthesize band signals      *
* Write out reconstructed imageaa*
***********************************************************************
subroutine subband(inimg, outimg, nx, ny)

   integer raw, col

c   raw=number of rows of input image
   col=number of columns of input image
***********************************************************************
* CHANGE raw and col values for different sized images*
***********************************************************************
   parameter (raw=400, col=512)

   real coff1(-20:20), coff2(-20:20), coff3(-20:20), coff4(-20:20)
   character*80 input_file
   common /if1/ if1
   common /ina/ input_file
   common /a/ coff1, coff2, coff3, coff4, ltap1, mtap1, ltap2, mtap2 &
       , ltap3, mtap3, ltap4, mtap4
real inimg(nx,ny)
real a1(200,256),a2(200,256),a3(200,256),a4(200,256)
real outimg(400,512)
real b1(raw/4,col/4),b2(raw/4,col/4)
real b3(raw/4,col/4),b4(raw/4,col/4)
real e1(raw/2,col/2)

input_file='FILTERS/inmf8'

write(*,*) 'subband analysis'
call analysis256(inimg,a1,a2,a3,a4)
call analysis128(a1,b1,b2,b3,b4)
call synthesis128(b1,b2,b3,b4,e1)
call synthesis256(e1,a2,a3,a4,outimg,inimg)

return
end

SUBROUTINE READ
THIS SUBROUTINE READS THE FILTER COEFFICIENTS
subroutine readf
real coff1(-20:20),coff2(-20:20),coff3(-20:20),coff4(-20:20)

common /a/ coff1,coff2,coff3,coff4,ltap1,mtap1,ltap2,mtap2
&
   ,ltap3,mtap3,ltap4,mtap4

    call openf
    write(*,*) 'reading filter coefficients'
    read(11,*) ltapl
    c
    write(*,*) ltapl
    read(11,*) mtapl
    do 10 i=ltapl,mtapl
       10     read(11,*) coff1(i)
    c
    read(11,*) ltap2
    read(11,*) mtap2
    do 20 i=ltap2,mtap2
       20     read(11,*) coff2(i)
    c
    read(11,*) ltap3
    read(11,*) mtap3
    do 30 i=ltap3,mtap3
       30     read(11,*) coff3(i)
    c
    read(11,*) ltap4
    read(11,*) mtap4
    do 40 i=ltap4,mtap4
       40     read(11,*) coff4(i)
    c

close (11)

RETURN
END

*******************************************************************************

subroutine openf
character*80 input_file
common/ina / input_file
write(*,*) 'Opening input_file'
open (11,file=input_file,status='old')
write(*,*), 'file opened'
return
end

********************************************************************************
subroutine analysis256(inimg, llband, lhband, hlband, hhband)

integer raw, col
parameter(raw=400, col=512)

real coff1(-20:20), coff2(-20:20), coff3(-20:20), coff4(-20:20)

common /a/ coff1, coff2, coff3, coff4, ltap1, mtap1, ltap2, mtap2
& , ltap3, mtap3, ltap4, mtap4

c these are the four subband
real llband(raw/2, col/2), lhband(raw/2, col/2)
& , hlband(raw/2, col/2), hhband(raw/2, col/2)

c these are the high and low bands
real lband(raw, col/2), hband(raw, col/2)

c input and output images
real inimg(raw, col)

nx=raw
ny=col

call rfilter(coff1, inimg, lband, nx, ny, ltap1, mtap1)
call rfilter(coff2, inimg, hband, nx, ny, ltap2, mtap2)
ny=ny/2
call cllfilter(coff1, lband, llband, nx, ny, ltap1, mtap1)
call clhfilter(coff2,lband,lhband,nx,ny,ltap2,mtap2)
call chrfilter(coff1,hband,hlband,nx,ny,ltap1,mtap1)
call chhfilter(coff2,hband,hhband,nx,ny,ltap2,mtap2)
return
end

******************************************************************************

subroutine analysis128(inimg,llband,lhband,hlband,hhband)
integer raw,col
parameter(raw=200,col=256)
common /ifld/ ifld
integer motionv(50,64),ifld
common /motionv/ motionv

real coff1(-20:20),coff2(-20:20),coff3(-20:20),coff4(-20:20)
common /a/ coff1,coff2,coff3,coff4,ltap1,mtap1,ltap2,mtap2
 & ,ltap3,mtap3,ltap4,mtap4

c these are the four subband
real llband(raw/2,col/2),lband(raw/2,col/2)
 & ,lhband(raw/2,col/2),hhband(raw/2,col/2)

c these are the high and low bands
real lband(raw,col/2),hband(raw,col/2)

c input and output images
real inimg(raw,col)
x=nx
y=ny
call rfilter(coff1,inimg,lband,nx,ny,ltap1,mtap1)
call rfilter(coff2,inimg,hband,nx,ny,ltap2,mtap2)
ny = ny/2

call cllllflter(coff1, lband, llband, nx, ny, ltap1, mtap1)
call clllhfilt(err, coff2, lband, lhband, nx, ny, ltap2, mtap2)
call cllhlfilter(coff1, hband, hlband, nx, ny, ltap1, mtap1)
call cllhhfilter(coff2, hband, hhband, nx, ny, ltap2, mtap2)

return
end

subroutine rfilter(f, a1, a2, raw, col, ltap, mtap)
integer col, raw, ltap, mtap
real a1(raw, col), a2(raw, col/2), f(-20:20)

do 20 i=1, raw
  do 20 j=2, col, 2
    a2(i, j/2) = 0
    do 20 k=ltap, mtap
      jk = j + k
      if (jk.le.0) jk = col + jk
      if (jk.gt.col) jk = jk - col
      a2(i, j/2) = a2(i, j/2) + a1(i, jk) * f(k)
  20   continue
return
end

subroutine cfilter(f, a1, a2, raw, col, ltap, mtap, jk)
integer col, raw, ltap, mtap, jk
real a1(raw, col), a2(raw/2, col), f(-20:20)

do 20 i=1, col
  do 20 j=2, raw, 2
    a2(j/2, i) = 0
    do 20 k=ltap, mtap
      jk = j + k
      if (jk.le.0) jk = raw + jk
      a2(j/2, i) = a2(j/2, i) + a1(i, jk) * f(k)
  20   continue
return
end
if(jk.gt.raw) jk=jk-raw

a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
20 continue

return
end

*********** LL FILTER***********************************

subroutine cllfilter(f,al,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
common /ifl/ ifl
real a1(raw,col),a2(raw/2,col),f(-20:20)
character*1 pimm(200*256)
parameter(nx=200,ny=256)

do 20 i=1,col
   do 20 j=2,raw,2
      a2(j/2,i)=0
      do 20 k=ltap,mtap
         jk=j+k
         if(jk.le.0) jk=raw+jk
         if(jk.gt.raw) jk=jk-raw

         a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
      20 continue
   c open(99,file='LL',access='direct',form='unformatted'
   c + ,recl=nx*ny)
   c do 690 i=1,nx
   c do 691 j=1,ny
   c ip=int(a2(i,j))+128
   c if(ip.gt.255) ip=255
   c if (ip.lt.0) ip=0
   c if(ip.gt.128) ip=ip-255
   c kk=j+(i-1)*ny
   c pimm(kk)=char(ip)
691 continue
690 continue
   c write(99,rec=ifl) (pimm(j),j=1,nx*ny)
   c close(99)
return
end

*********** LLLL FILTER***********************************
subroutine clllllfilter(f,a1,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
real a1(raw,col),a2(100,128),f(-20:20)
common /hist1/ hist1
real hist1(3,512)
common /ifl/ ifl
common /entropy1/entropy1
character*1 pimm(100*128)
parameter(nx=100,ny=128)

   do 20 i=1,col
   do 20 j=2,raw,2
      a2(j/2,i)=0
   do 20 k=ltap,mtap
      jk=j+k
      if(jk.le.0) jk=raw+jk
      if(jk.gt.raw) jk=jk-raw
      a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
20   continue

   call vec_quan1(a2)

   open(99,file='LLLL',access='direct',form='unformatted'
   + ,recl=nx*ny)
   do 690 i=1,nx
      do 691 j=1,ny
         ip=int(a2(i,j))+128
         if(ip.gt.255) ip=255
         if(ip.lt.0) ip=0
         if(ip.gt.128) ip=ip-255
         kk=j+(i-1)*ny
         pimm(kk)=char(ip)
691    continue
690   continue
   write(99,rec=ifl) (pimm(j),j=1,nx*ny)
   close(99)
   call vbitrates1(hist1,entropy1,3,512)
   write(*,*) 'entropy1=',entropy1
return
end
**** LLLH FILTER************

subroutine clllhfilter(f,al,a2,raw,col,ltap,mtap)
    integer col,raw,ltap,mtap,jk
    real pimmi(12800),pimm2(12800)
    real a1(raw,col),a2(raw/2,col),f(-20:20)
    common /hist2/ hist2
    common /entropy2/ entropy2
    real hist2(3,512)
    common /if1/ if1
    character*1  pimm(100*128)
    parameter(nx=100,ny=128)
    do 20 i=1,col
    do 20 j=2,raw,2
        a2(j/2,i)=0
    do 20 k=ltap,mtap
        jk=j+k
        if(jk.le.0) jk=raw+jk
        if(jk.gt.raw) jk=jk-raw
        a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
    20 continue
    call vec_quan2(a2)

    c     open(99,file='LLLH',access='direct',form='unformatted'
    c         ,recl=nx*ny)
    c     do 690 i=1,nx
    c     do 691 j=1,ny
    c     ip=int(a2(i,j))+128
    c     if(ip.gt.255) ip=255
    c     if (ip.lt.0) ip=0
    c     if(ip.gt.128) ip=ip-255
    c     kk=j+(i-1)*ny
    c     pimm(kk)=char(ip)
    c691 continue
    c690 continue
    c     write(99,rec=if1) (pimm(j),j=1,nx*ny)
    c     close(99)
    c     do 1 i=1,100
    c     do 1 j=1,128
kk=j+(i-1)*128
pimm1(kk)=a2(i,j)
write(60,*) pimm1(kk)
c1 continue
call vbitrates2(hist2,entropy2,3,512)
write(*,*) 'entropy2=',entropy2
return
end

********** LLHL FILTER******************************
subroutine cllhlfilter(f,a1,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
real a1(raw,col),a2(raw/2,col),f(-20:20)
common /ifl/ ifl
common /hist3/ hist3
common /entropy3/entropy3
real hist3(3,512)
character*1 pimm(100*128)
parameter(nx=100,ny=128)
do 20 i=1,col
   do 20 j=2,raw,2
      a2(j/2,i)=0
      do 20 k=ltap,mtap
         jk=j+k
         if(jk.le.0) jk=raw+jk
         if(jk.gt.raw) jk=jk-raw
         a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
20   continue
   call vec_quan3(a2)
   do 690 i=1,nx
      do 691 j=1,ny
         ip=int(a2(i,j))+128
         if(ip.gt.255) ip=255
         if (ip.lt.0) ip=0
         if(ip.gt.128) ip=ip-255
98   open(99,file='LLHL',access='direct',form='unformatted'
97      + ,recl=nx*ny)
do 690 i=1,nx
   do 691 j=1,ny
      ip=int(a2(i,j))+128
      if(ip.gt.255) ip=255
      if (ip.lt.0) ip=0
      if(ip.gt.128) ip=ip-255
**LLHH FILTER**

Subroutine `cllhhfilter(f, a1, a2, raw, col, ltap, mtap)`

```fortran
integer col, raw, ltap, mtap, jk
real a1(raw, col), a2(raw/2, col), f(-20:20)
common /ifl/ ifl
parameter(nx=100, ny=128)

do 20 i=1, col
  do 20 j=2, raw, 2
    a2(j/2, i) = 0
    do 20 k=ltap, mtap
      jk=j+k
      if(jk.le.0) jk=raw+jk
      if(jk.gt.raw) jk=jk-raw
    c     a2(j/2, i) = a2(j/2, i) + a1(jk, i) * f(k)
    a2(j/2, i) = 0.0
  20     continue

return
end
```

**LH FILTER**

Subroutine `clhfilter(f, a1, a2, raw, col, ltap, mtap)`

```fortran
integer col, raw, ltap, mtap, jk
real a1(raw, col), a2(raw/2, col), a6(200, 256), f(-20:20)
common /ifl/ ifl
character*1 pimm(200*256)
```
parameter(nx=200,ny=256)

do 20 i=1,col
  do 20 j=2,raw,2
    a2(j/2,i)=0
  do 20 k=ltap,mtap
    jk=j+k
    if(jk.le.0) jk=raw+jk
    if(jk.gt.raw) jk=jk-raw
    a2(j/2,i)=0
    a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
  continue
20 continue

open(99,file='LH',access='direct',form='unformatted',recl=nx*ny)
do 690 i=1,nx
do 691 j=1,ny
  ip=int(a2(i,j))+128
  if(ip.gt.255) ip=255
  if(ip.lt.0) ip=0
  if(ip.gt.128) ip=ip-255
  kk=j+(i-1)*ny
  pimm(kk)=char(ip)
691 continue
690 continue
write(99,rec=ifl) (pimm(j),j=1,nx*ny)
close(99)
call arl(a2,200,256,a6,4,4)
do 35 i=1,200
do 35 j=1,256
  a2(i,j)=a6(i,j)
continue
return
end

****************HL FILTER**************************
subroutine chlfilter(f,a1,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
real a1(raw,col),a2(raw/2,col),f(-20:20)
common /ifl/ ifl
character*1 pimm(200*256)
parameter(nx=200,ny=256)
do 20 i=1,col
    do 20 j=2,raw,2
        a2(j/2,i)=0
        do 20 k=ltap,mtap
            jk=j+k
            if(jk.1e.0) jk=raw+jk
            if(jk.gt.raw) jk=jk-raw
        c         a2(j/2,i)=a2(j/2,0)+a1(jk,i)*f(k)
        a2(j/2,i)=0.0
    20 continue
    call arl(a2,20,256,a7,2,2)
    do 35 i=1,200
    do 35 j=1,256
        a2(i,j)=a7(i,j)
        write(13,*) ((a2(i,j),j=1,256),i=1,200)
        open(99, file='HL'acc, direct, unformatted'
        do 690 i=1,nx
            do 691 j=1,ny
                ip=int(a2(i,j))+128
                if(ip.gt.255) ip=255
                if(ip.lt.0) ip=0
                if(ip.gt.128) ip=ip-255
                kk=j+(i-1)*ny
                pimm(kk)=char(ip)
            c691 continue
            c690 continue
        c         write(99, rec=ifl) (pimm(j), j=1,nx*ny)
    close(99)
return
end

********** HH FILTER **********
subroutine chhfilter(f,a1,a2,raw,col,ltap,mtap)
    integer col,raw,ltap,mtap,jk
    real a1(raw,col),a2(200,256),f(-20:20)
    common /ifl/ ifl
    real a8(200,256)
    character*1 pimm(200+256)
    parameter(nx=200,ny=256)
    do 20 i=1,col
do 20 j=2,raw,2
   a2(j/2,i)=0
do 20 k=ltap,mtap
   jk=j+k
   if(jk.le.0) jk=raw+jk
   if(jk.gt.raw) jk=jk-raw

   a2(j/2,i)=a2(j/2,i)+a1(jk,i)*f(k)
a2(j/2,1)=0.0
20  continue

write(*,*) ifl
call arl(a2,200,256,a8,16,16)
do 35 i=1,200
   do 35 j=1,256
      a2(i,j)=a8(i,j)
35
open(99,file='HH',access='direct',form='unformatted'
+ ,recl=nx*ny)
do 690 i=1,nx
   do 691 j=1,ny
      ip=int(a2(i,j))+128
      if(ip.gt.255) ip=255
      if (ip.lt.0) ip=0
      if(ip.gt.128) ip=ip-255
      kk=j+(i-1)*ny
      pimm(kk)=char(ip)
691  continue
690  continue
write(99,rec=ifl) (pimm(j),j=1,nx*ny)
close(99)
return
end

******************************************************************************
subroutine vec_quanl(pic)
******************************************************************************
c   pic: picture o be coded (100X128)
real pic(100,128)
integer motionv(50,64)
real tvector(4)
common /hist1/ hist1
integer hist1(3,512)
common /motionv/ motionv
real b1v1(512,4),b1v2(512,4),b1v3(512,4)
common /vqcodebook1/ b1v1,b1v2,b1v3

do 191 i=1,3
   do 191 j=1,512
      hist1(i,j)=0
   191 continue

nn=0
do 10 i=1,50
   do 10 j=1,64
      if(motionv(i,j).ge.5) then
         do 20 k=1,2
            do 20 l=1,2
               tvector(2*(k-1)+l)=pic((i-1)*2+k,(j-1)*2+l)
            20 continue
            mm=nn+3
      else if(motionv(i,j).ge.3) then
         do 21 k=1,2
            do 21 l=1,2
               tvector(2*(k-1)+l)=pic((i-1)*2+k,(j-1)*2+l)
            21 continue
            mm=nn+2
      else if(motionv(i,j).ge.1) then
         do 22 k=1,2
            do 22 l=1,2
               tvector(2*(k-1)+l)=pic((i-1)*2+k,(j-1)*2+l)
            22 continue
            mm=nn+1
      else
         do 33 k=1,2
            do 33 l=1,2
               pic((i-1)*2+k,(j-1)*2+l)=0.0
            33 continue
            mm=0
      endif
   else
      if(mm.eq.1) then
         call vquantizer(tvector,b1v1,ivecnum)
         hist1(1,ivecnum) = hist1(1,ivecnum)+1
   endif
   10 continue
else if(mm.eq.2) then
    call vquantizer(tvector,b1v2,ivecnum)
    hist1(2,ivecnum) = hist1(2,ivecnum)+1

else if(mm.eq.3) then
    call vquantizer(tvector,b1v3,ivecnum)
    hist1(3,ivecnum) = hist1(3,ivecnum)+1
endif

if(mm.ne.0) then
    do 44 k=1,2
    do 44 l=1,2
        pic((i-1)*2+k,(j-1)*2+l) = tvector(2*(k-1)+1)
    44    continue
endif

10    continue

return
end

*********************************************************
subroutine vec_quan2(pic)
*********************************************************
c    pic: picture to be coded (100X128)

real pic(100,128)
integer motionv(50,64)
integer motionv1(25,32)

real tvector(16)
common /hist2/ hist2
integer hist2(3,512)
common /motionv/ motionv
real b2v1(512,16),b2v2(512,16),b2v3(512,16)
common /vqcodebook2/ b2v1,b2v2,b2v3

do 191 i=1,3
    do 191 j=1,512
        hist2(i,j)=0
    191    continue

do 50 i=1,25
    do 50 j=1,32
        not1=0

do 51 k=i*2-1,2*i
  do 51 l=2*j-1,2*j
    notl =notl+motionv(k,l)
  continue
motionv1(i,j)=(notl/4)
continue

nn=0
do 10 i=1,25
  do 10 j=1,32
    if(motionv1(i,j).ge.5) then
      do 20 k=1,4
        do 20 l=1,4
          tvector(4*(k-1)+1)=pic((i-1)*4+k,(j-1)*4+1)
      continue
      mm=nn+3
    else if(motionv1(i,j).ge.3) then
      do 21 k=1,4
        do 21 l=1,4
          tvector(4*(k-1)+1)=pic((i-1)*4+k,(j-1)*4+1)
      continue
      mm=nn+2
    else if(motionv1(i,j).ge.1) then
      do 22 k=1,4
        do 22 l=1,4
          tvector(4*(k-1)+l)=pic((i-1)*4+k,(j-1)*4+1)
      continue
      mm=nn+1
    else
      do 33 k=1,4
        do 33 l=1,4
          pic((i-1)*4+k,(j-1)*4+1)=0.0
      continue
      mm=0
    endif
  endif
  if(mm.eq.1) then
    call vquantizer3(tvector,b2v1,ivecnum)
    hist2(1,ivecnum) = hist2(1,ivecnum)+1
  else if(mm.eq.2) then
    call vquantizer3(tvector,b2v2,ivecnum)
  endif
hist2(2,ivecnum) = hist2(2,ivecnum)+1

else if(mm.eq.3) then
   call vquantizer3(tvector,b2v3,ivecnum)
   hist2(3,ivecnum) = hist2(3,ivecnum)+1
endif

if(mm.ne.0) then
   do 44 k=1,4
   do 44 l=1,4
      pic((i-1)*4+k,(j-1)*4+l) = tvector(4*(k-1)+l)
   44     continue
   endif
   continue

return
end

******************************************************************************
subroutine vec_quan3(pic)
c    pic: picture to be coded (100X128)

real pic(100,128)
integer motionv(50,64)
integer motionv1(25,32)
real tvector(16)
common /hist3/ hist3
integer hist3(3,512)
common /motionv/ motionv
real b3v1(512,16),b3v2(512,16),b3v3(512,16)
common /vqcodebook3/ b3v1,b3v2,b3v3

   do 191 i=1,3
   do 191 j=1,512
      hist3(i,j)=0
   191   continue
   do 50 i=1,25
   do 50 j=1,32
      notl=0
   do 51 k=i*2-1,2*i
   do 51 l=2*j-1,2*j
      notl =notl+motionv(k,l)
   51   continue

motionv1(i,j) = (notl/4)

continue

nn=0
do 10 i=1,25
  do 10 j=1,32
    if (motionv1(i,j) .ge. 5) then
      do 20 k=1,4
        do 20 l=1,4
          tvector(4*(k-1)+l) = pic((i-1)*4+k,(j-1)*4+l)
        20      continue
      mm=nn+3
    else if (motionv1(i,j) .ge. 3) then
      do 21 k=1,4
        do 21 l=1,4
          tvector(4*(k-1)+l) = pic((i-1)*4+k,(j-1)*4+l)
        21      continue
      mm=nn+2
    else if (motionv1(i,j) .ge. 1) then
      do 22 k=1,4
        do 22 l=1,4
          tvector(4*(k-1)+l) = pic((i-1)*4+k,(j-1)*4+l)
        22      continue
      mm=nn+1
    else
      do 33 k=1,4
        do 33 l=1,4
          pic((i-1)*4+k,(j-1)*4+l) = 0.0
        33      continue
      mm=0
    endif
  endif
  if (mm .eq. 1) then
    call vquantizer3(tvector,b3v1,ivecnum)
    hist3(1,ivecnum) = hist3(1,ivecnum)+1
  else if (mm .eq. 2) then
    call vquantizer3(tvector,b3v2,ivecnum)
    hist3(2,ivecnum) = hist3(2,ivecnum)+1
  else if (mm .eq. 3) then
    call vquantizer3(tvector,b3v3,ivecnum)
    hist3(3,ivecnum) = hist3(3,ivecnum)+1
  endif
if(mm.ne.0) then
   do 44 k=1,4
   do 44 l=1,4
       pic((i-1)*4+k,(j-1)*4+l) = tvector(4*(k-1)+l)
   44        continue
   endif
10       continue

return
end

*******************************************************************************
subroutine vec_quant4(enimg,n,hist4,L)
real testv(16)
real enimg(3200)
integer hist4(L)
integer ivecnum4
real b4v1(256,16),b4v2(256,16),b4v3(512,16),b4v4(512,16)
common /vqcodebook4/ b4v1,b4v2,b4v3,b4v4

do 17 j=1,L
   hist4(j)=0
17       continue

do 100 i=0,3184,16
   k=0
      do 150 ii=i+1,i+16
         k=k+1
         testv(k) = enimg(ii)
150      continue

   if (n.eq.1) then
      call vquant4(testv,b4v1,ivecnum4,L)
   else if (n.eq.2) then
      call vquant4(testv,b4v2,ivecnum4,L)
   endif
100     continue
else if (n.eq.3) then
  call vquant4(testv,b4v3,ivecnum4,L)
else if (n.eq.4) then
  call vquant4(testv,b4v4,ivecnum4,L)
endif

hist4(ivecnum4)=hist4(ivecnum4)+1

k1=0
  do 170 jj=i+1,i+16
    k1=k1+1
    enimg(jj) = testv(k1)
  170 continue

100 continue

return
end

******************************************************************************
subroutine vquantizer(testv,codebook,ivecnu)
c  Best Matching of vector
  real testv(4)
  real codebook(512,4)

rdiff = 1000000.0
ivecnu = 0

  do 110 m = 1,512
    adiff = 0
    do 120 n = 1,4
      adiff = adiff + (testv(n) - codebook(m,n))**2
    120 continue
    if (adiff .lt. rdiff) then
      rdiff = adiff
    endif
  110 continue
ivecnu = m
endif
continue
do 130 n = 1,4
testv(n) = codebook(ivecnu,n)
continue
return
end

****************************************************
subroutine vquantizer3(testv,codebook,ivecnu)
c Best Matching of vector
real testv(16)
real codebook(512,16)
rdiff = 1000000.0
ivecnu = 0
do 110 m = 1,512
adiff = 0
do 120 n = 1,16
adiff = adiff + (testv(n) - codebook(m,n))**2
continue
if (adiff .lt. rdiff) then
rdiff = adiff
ivecnu = m
endif
continue
do 130 n = 1,16
testv(n) = codebook(ivecnu,n)
continue
return
end

subroutine vquant4(testv,codebook,ivecnu,L)
c Best Matching of vector
real testv(16)
real codebook(L,16)
rdiff = 1000000.0
ivecnu = 0

do 110 m = 1,L
    adiff = 0
    do 120 n = 1,16
        adiff = adiff + (testv(n) - codebook(m,n))**2
    120 continue
    if (adiff .lt. rdiff) then
        rdiff = adiff
        ivecnu = m
    endif
110 continue

do 130 n = 1,16
    testv(n) = codebook(ivecnu,n)
130 continue

return
end

********************************************************************************
c this subroutine calculate the entropy of each band
c and find the probability of each code
********************************************************************************

subroutine vbitrates1(ic,bitrate,raw,col)

common /gtotal/ gtotal
integer ic(raw,col),raw,col
real entropy(3),sum(512),pr(512)

gtotal=0
bitrate=0
do 10 m=1,3
    total=0
    do 20 n=1,512
        sum(n)=ic(m,n)
        total=total+sum(n)
    20 continue
 10 continue
entropy(m)=0.0
do 30 n=1,512
    pr(n)=sum(n)/total
    if(pr(n).gt.0) then
        br=pr(n)*xlog2(1.0/pr(n))
        entropy(m)=entropy(m)+br
    endif
30  continue
bitrate=bitrate+entropy(m)*total
write(*,*) 'total = ',total
gtotal=gtotal+total
10  continue
write(*,*) 'gtotal = ',gtotal
write(*,*) 'ventropy = ',(entropy(i),i=1,3)
write(*,*) 'bitrate = ', bitrate
return
end

******************************************************************************

subroutine vbitrates2(ic,bitrate,raw,col)

integer ic(raw,col),raw,col
real entropy(3),sum(512),pr(512)

gtotal=0
bitrate=0
do 10 m=1,3

total=0
10  continue

entropy(m)=0.0
do 30 n=1,512
    pr(n)=sum(n)/total
    if(pr(n).gt.0) then
        br=pr(n)*xlog2(1.0/pr(n))
        entropy(m)=entropy(m)+br
    endif
30  continue
endif

30   continue
  
bitrate=bitrate+entropy(m)*total
write(*,*) 'total = ',total
gtotal=gtotal+total
10   continue
  c         bitrate=(gtotal/800)*(9./256)

write(*,*) 'gtotal = ',gtotal
write(*,*) 'ventropy = ',(entropy(i),i=1,3)
write(*,*) 'bitrate = ', bitrate
return
end

*****************************************************************************

subroutine vbitrates3(ic,bitrate,raw,col)

integer ic(raw,col),raw,col
real entropy(3),sum(512),pr(512)

gtotal=0
bitrate=0
do 10 m=1,3

    total=0
  do 20 n=1,512
      sum(n)=ic(m,n)
      total=total+sum(n)
20    continue
  c

    entropy(m)=0.0
  do 30 n=1,512
      pr(n)=sum(n)/total
      if(pr(n).gt.0) then
        br=pr(n)*xlog2(1.0/pr(n))
        entropy(m)=entropy(m)+br
      endif
 30    continue

bitrate=bitrate+entropy(m)*total
write(*,*) 'total = ',total
gtotal=gtotal+total
10 continue

c bitrate=(gtotal/800)*(9./256.)

write(*,*) 'gtotal = ',gtotal
write(*,*) 'ventropy = ',(entropy(i),i=1,3)
write(*,*) 'bitrate = ', bitrate
return
end

************************************************************

subroutine vbitrates4(ic,bitrate,col)

integer ic(col),col
real entropy,sum(512),pr(512)

bitrate=0

total=0
do 20 n=1,col
        sum(n)=ic(n)
        total=total+sum(n)
20 continue

entropy=0.0
do 30 n=1,col
        pr(n)=sum(n)/total
        if(pr(n).gt.0) then
                br=pr(n)*xlog2(1.0/pr(n))
                entropy=entropy+br
        endif
30 continue

bitrate=entropy*total

write(*,*) 'entropyarl = ',entropy
write(*,*) 'total = ',total
write(*,*) 'bitrate = ', bitrate

return
end

******************************************************************************
function xlog2(x)
real x
xlog2=alog(x)/alog(2.0)
return
end

******************************************************************************
subroutine bitrates2(ic,entropy,raw,col)
******************************************************************************
integer ic(raw,col),raw,col
real entropy,sum(0:169),pr(0:169)
do 20 n=0,169
sum(n)=0.0
20 continue

do 10 i=1,raw
do 10 j=1,col
  k=ic(i,j)
  sum(k)=sum(k)+1
10 continue
entropy=0.0
total=real(raw*col)
do 30 n=0,169
  pr(n)=sum(n)/total
  if(pr(n).gt.0) then
    br=pr(n)*xlog2(1.0/pr(n))
    entropy=entropy+br
  endif
30 continue

write(*,*) 'xmentropy = ',entropy
write(*,*) 'pr = ',(pr(i),i=1,169)
return
end
subroutine ccfilter(f,a1,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
real a1(raw,col),a2(raw,col),f(-20:20)
do 20 i=1,col
   do 20 j=1,raw
      a2(j,i)=0
      do 20 k=ltap,mtap
         jk=j+k
         if(jk.le.0) jk=raw+jk
         if(jk.gt.raw) jk=jk-raw
         a2(j,i)=a2(j,i)+a1(jk,i)*f(k)
20  continue
return
end

subroutine rcfilter(f,a1,a2,raw,col,ltap,mtap)
integer col,raw,ltap,mtap,jk
real a1(raw,col),a2(raw,col),f(-20:20)
do 20 i=1,raw
   do 20 j=1,col
      a2(i,j)=0
      do 20 k=ltap,mtap
         jk=j+k
         if(jk.le.0) jk=col+jk
         if(jk.gt.col) jk=jk-col
         a2(i,j)=a2(i,j)+a1(i,jk)*f(k)
20  continue
return
end

subroutine cinter(in,out,nraw,ncol)
integer nraw,ncol
real in(nraw,ncol),out(nraw*2,ncol)
do 20 j=1,ncol
   do 20 i=1,nraw
      out(2*i-1,j)=in(i,j)
      out(2*i,j)=0.0
c       out(2*i,j)=in(i,j)
c       out(2*i-1,j)=0.0
20  continue
return
end

subroutine rinter(in,out,nraw,ncol)
integer nraw,ncol
real in(nraw,ncol),out(nraw,2*ncol)
do 20 j=1,ncol
   do 20 i=1,nraw
      out(i,2*j-1)=in(i,j)
      out(i,2*j)=0.0
   c      out(i,2*j)=in(i,j)
c      out(i,2*j-1)=0.0
20  continue
return
end

c---------------------------------------------------------------

subroutine synthesis256(llband,lhband,hlband,hhband,outimg,
+      inimg)
character*1 pimm(400*512)
real inimg(400,512)
integer raw,col
parameter(raw=400,col=512)
parameter(nx=400,ny=512)

c input and output images
   real outimg(raw,col)

c these are the four subband
   real lli(raw,col/2),lhi(raw,col/2),hli(raw,col/2),
&      hhband(raw/2,col/2)
   & hhi(raw,col/2),llo(raw,col/2),lho(raw,col/2),hlo(raw,col/2),
&      hho(raw,col/2)
real li(raw,col/2),lo(raw,col),hi(raw,col/2),
& ho(raw,col)

real limg(raw,col),himg(raw,col)

real coff1(-20:20),coff2(-20:20),coff3(-20:20),coff4(-20:20)

common /a/ coff1,coff2,coff3,coff4,ltap1,mtap1,ltap2,mtap2
&
   ,ltap3,mtap3,ltap4,mtap4

c______________________________
nraw=raw
ncol=col

call cinter(llband,lli,raw/2,col/2)
call ccfilter(coff4,lli,llo,raw,col/2,ltap4,mtap4)

call cinter(lhband,lhi,raw/2,col/2)
call ccfilter(coff3,lhi,lho,raw,col/2,ltap3,mtap3)

call cinter(hlband,hli,raw/2,col/2)
call ccfilter(coff4,hli,hho,raw,col/2,tap4,mtap4)

call cinter(hhband,hhi,raw/2,col/2)
call ccfilter(coff3,hhi,hho,raw,col/2,ltap3,mtap3)

c
do 10 i=1,raw
do 10 j=1,col/2
   li(i,j)=llo(i,j)+lho(i,j)
   li(i,j)=llo(i,j)

   hi(i,j)=hlo(i,j)+hho(i,j)
   hi(i,j)=hlo(i,j)
   hi(i,j)=0.0
10 continue

call rinter(li,lo,raw,col/2)
call rcfilter(coff4,lo,limg,raw,col,ltap4,mtap4)

call rinter(hi,ho,raw,col/2)
call rcfilter(coff3,ho,himg,raw,col,ltap3,mtap3)

do 20 i=1,raw
  do 20 j=1,col
    outimg(i,j)=limg(i,j)
  continue

+open(99,file='im',access='direct',form='unformatted'
  ,recl=nx*ny)
+do 690 i=1,nx
+  do 691 j=1,ny
+    ip=int(outimg(i,j))+128
+    if(ip.gt.255) ip=255
+    if (ip.lt.0) ip=0
+    if(ip.gt.128) ip=ip-255
+    kk=j+(i-1)*ny
+    pimm(kk)=char(ip)
  continue
  continue
+write(99,rec=1) (pimm(j),j=1,nx*ny)
+close(99)

return
end

**********************************************************************
* SYNTHESES FILTER FOR 128*100 IMAGES*
**********************************************************************

subroutine synthesis128(llband,lhband,hlband,hhband,outimg)

integer raw,col
parameter(raw=200,col=256)

c input and output images
  real outimg(raw,col)

c these are the four subband
  real llband(raw/2,col/2),lhband(raw/2,col/2)
  & hhband(raw/2,col/2)
&  

real lli(raw,col/2),lhi(raw,col/2),hli(raw,col/2),
& hhi(raw,col/2),llo(raw,col/2),lho(raw,col/2),hlo(raw,col/2),
& hho(raw,col/2)

real li(raw,col/2),lo(raw,col),hi(raw,col/2),
& ho(raw,col)

real limg(raw,col),himg(raw,col)
real coff1(-20:20),coff2(-20:20),coff3(-20:20),coff4(-20:20)

common /a/ coff1,coff2,coff3,coff4,ltapl,mtapl,ltap2,mtap2
and
,ltap3,mtap3,ltap4,mtap4

---

nraw=raw
ncol=col

call cinter(llband,lli,raw/2,col/2)
call ccfiter(coff4,lli,llo,raw,col/2,ltap4,mtap4)

call cinter(lhband,lhi,raw/2,col/2)
call ccfiter(coff3,lhi,lho,raw,col/2,ltap3,mtap3)

call cinter(hlband,hli,raw/2,col/2)
call ccfiter(coff4,hli,hlo,raw,col/2,tap4,mtap4)

call cinter(hhband,hhi,raw/2,col/2)
call ccfiter(coff3,hhi,hho,raw,col/2,tap3,mtap3)

cdo 10 i=1,raw
do 10 j=1,col/2
li(i,j)=llo(i,j)+lho(i,j)
hi(i,j)=hlo(i,j)
10 continue

call rinter(li,lo,raw,col/2)
call rcfiter(coff4,lo,limg,raw,col,ltap4,mtap4)

call rinter(hi,ho,raw,col/2)
call rcfiter(coff3,ho,himg,raw,col,ltap3,mtap3)
do 20 i=1,raw
    do 20 j=1,col
        outimg(i,j)=1*(limg(i,j)+himg(i,j))
    20 continue

return
end

******************************************************************************
REFERENCES


