Adaptive Discrete Cosine Transform Image Compression Applied to Visual Flight Simulators

1986

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ADAPTIVE DISCRETE COSINE TRANSFORM
IMAGE COMPRESSION APPLIED
TO VISUAL FLIGHT SIMULATORS

BY

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ABSTRACT

A visual flight simulator requires a huge amount of image data to be stored in the database. To make a photo-based system feasible an image compression scheme must be devised to compress the data.

An adaptive discrete cosine transform (DCT) technique is used to compress 24 bit color images to an average of 3 bits per pixel. The bits for the image are distributed based on the relative activity in different parts of the scene. A software implementation of this technique is applied to some sample database images. Results and error analysis are presented.
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<td>Red, Green, Blue color data</td>
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<td>BPP</td>
<td>Bits per pixel</td>
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<td>DCT</td>
<td>Discrete cosine transform</td>
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A database for a visual flight simulator can be made up of aerial photographs. These color photographs of rural and urban areas are high resolution (1 to 4 foot) and are stored as 24 bit per pixel (BPP) red (R), green (G) and blue (B) color quantization.

Because of the enormous amount of data needed for this database, it must be stored in a compressed form and decompressed as necessary. The decompression should be fairly simple and quick. The data needs to be compressed from 24 to 3 BPP average without degrading the image below acceptable levels. Since the application is for a visual flight simulator, the subjective image degradation is very important both in terms of absolute and relative error. The discrete cosine transform (DCT) technique is generally accepted as yielding a high compression ratio with a fairly low amount of operations required for decompression. An adaptive technique takes into account the variations of activity within a scene. Less bits are used to code areas of relative low activity, such as a desert, than would be used for areas of high activity, such as a city.
An optimal block size is determined, as well as the number of transform coefficients to be retained for acceptable results. Error measurement between the original and reconstructed images, both subjective and objective, is investigated.
CHAPTER I

REQUIREMENTS

The images to be compressed are high resolution color photographs to be used as database for a visual flight simulator. Donovan [1] has defined a requirement to store 50 billion pixels on disk for a high resolution flight simulator database. The data needed for the realtime image is retrieved and stored in memory boards in the simulator hardware. To keep the amount of memory needed to a reasonable amount, it is necessary to compress the data to an average of 3 bits per pixel. Since the 24 BPP color image is actually 8 BPP red, 8 BPP green and 8 BPP blue, each color is processed separately and is compressed to an average of 1 BPP. The decompression technique must require little hardware and minimal processing time.

A frequency domain transform technique, such as the discrete cosine transform, has advantage over a spatial domain one for compression because the transform contains
information about the entire image, in varying degrees, in each coefficient. Therefore, the coefficients having a lesser effect on the image can be eliminated, resulting in a data compression.

Also, any error term is spread throughout the image, perhaps making its effects less important when a coefficient is discarded. The adaptive DCT has a fairly simple decompression algorithm. Habbi [2] states that the cosine transform has been shown to have a better mean square error performance than the Fourier or Hadamard transforms, and is easier to implement than the Karhunen-Loeve.

Error analysis between the original and reconstructed images consist of both objective and subjective measurements. The objective error is calculated using a mean square error method. The subjective analysis will consider absolute and relative errors. Relative errors are color shifts between transform block, representing a change in error between pixels. Absolute error is an incorrect color.
The DCT technique is chosen because it is a fast algorithm to implement and has excellent compression ratios as Chen [3] states. The adaptive DCT breaks the image into transform blocks of $4 \times 4$, $8 \times 8$ or $16 \times 16$ pixels. The smaller transform blocks give greater adaptivity but require more processing.

The adaptivity is in distributing the bits over the image. The transform blocks are compared and assigned an average number of bits based on the activity within the block. These are termed the adaptive assignment codes (AAC).

The database for use with the adaptive DCT can be generated by processing a large group of images and calculating standard deviation matrices (SDM), bit assignment matrices (BAM) and quantization lookup tables (QLUTs). These then become part of the database and any images being compressed can access them. The DCT is
performed and the coefficients are normalized by the corresponding SDM. The corresponding BAM value points to the QLUT table to use and the normalized coefficient is the address to the table.

The output is the quantization code used to represent a particular coefficient. The adaptive assignment code is overhead information carried along with each block to be used for image reconstruction. The AAC is used to access the proper BAM and SDM files. The BAM value points to the proper inverse quantization table (IQLUT). The code stored as the compressed image is the address to the table. The output is the normalized DCT coefficient. This is multiplied by the corresponding SDM and the inverse transform is performed. The output of this is the reconstructed image.
CHAPTER III

IMPLEMENTATION

A block diagram of the adaptive coding scheme is shown in Figure 1. Because of the limited images available, there was no database generated of bit assignment matrices, standard deviation matrices and quantization lookup tables. These are calculated for the image being processed only. A copy of the code used in the implementation is included in the appendix.

Discrete Cosine Transform

The transform matrix \( C \) for the discrete cosine transform can be expressed for a \( N \times N \) transform block as:

\[
C = \frac{1}{2} N \begin{bmatrix} C_{jm} \end{bmatrix},
\]

where

\[
C_{jm} = \begin{cases} 
1 & m = 0 \\
2 \cos(2j + 1) \ast m \ast \pi / 2N, & j = 0, N-1; m = 1, N-1.
\end{cases}
\]
Figure 1. Adaptive DCT compression.
The two-dimensional transform is then

\[ T(m,n) = C \ast I(j,k) \ast C', \]

where

\( I(j,k) = \text{original pixel intensity at } j,k \)

and

\( T(m,n) = \text{transformed coefficients in position } m,n. \)

The transform converts the image data to a set of coefficients representing the energy distribution. Each coefficient contains information about the whole image. The dc term represents the average image brightness. The other coefficients are increasing frequency terms containing image edge information. The number of coefficients retained affects the resolution of the image.
Adaptive Assignment Code (AAC)

The image is divided into transform blocks of size $N \times N$. The energy content of each transform block is measured by the variance between its pixels. These energies are compared and the AAC is assigned as described in Pacelli [4] by:

$$
AAC_i = \begin{cases} 
\text{TRUNC}[X_i], & 1 < x < 9 \\
1, & x < 1 \\
8, & x > 9,
\end{cases}
$$

where

\begin{align*}
\text{TRUNC} &= \text{real to integer truncation}, \\
X_i &= \log_2(\text{SIG}_i^2/2) - D/N, \\
N &= \text{number of pixels per block}, \\
\text{SIG}_i^2 &= \text{variance of the } i\text{th transform block}, \\
D &= \text{distortion}
\end{align*}

and

$$
\sum_{i=1}^{N} AAC_i = N \times (\text{AAC for desired bit rate}).
$$

From Pacelli [4], the AACs for 1 BPP compression are defined as shown in Table 1.
<table>
<thead>
<tr>
<th>AAC</th>
<th>AVG BPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.375</td>
</tr>
<tr>
<td>2</td>
<td>.375</td>
</tr>
<tr>
<td>3</td>
<td>.6875</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>1.3125</td>
</tr>
<tr>
<td>6</td>
<td>1.625</td>
</tr>
<tr>
<td>7</td>
<td>1.9375</td>
</tr>
<tr>
<td>8</td>
<td>2.25</td>
</tr>
</tbody>
</table>
**Standard Deviation Matrices (SDM)**

The standard deviations are calculated between each coefficient in a transform block and the corresponding coefficients in other blocks assigned the same AAC. These eight resulting matrices are the SDMs. The SDMs are used to determine the bit assignment matrices (BAMs), or number of bits assigned to each coefficient for a particular AAC class. The coefficients of the DCT are normalized by the corresponding standard deviation.

**Bit Assignment Matrices (BAM)**

The BAMs allocate the bits per transform block between the coefficients in the block. The BAMs are calculated as in Pacelli [4] by:

\[ N_{ij} = \text{Trunc}[(\log_2 \Sigma_{ij}) - D], \]

where

- \( N_{ij} \) = \((i,j)\)th element in the BAM,
- \( \text{TRUNC} \) = real to integer truncation function,
- \( \Sigma_{ij} \) = Standard deviation truncation function from the \((i,j)\)th position of the SDM

and

- \( D \) = distortion term, incremented on successive iterations.

The number of bits assigned to each coefficient in a block cannot exceed the total number of bits allocated to that block by the AAC. Therefore, iterations are done so
that

\[
\sum_{i=1}^{\text{Row}} \sum_{j=1}^{\text{Col}} N_{ij} = N_{\text{tot}},
\]

where

Row = the number of coefficients per row of a block,
Col = the number of coefficients per column of a block,
N_{\text{tot}} = the number of bits corresponding to the AAC, multiplied by the number of coefficients in the block.

Quantization

The normalized coefficients are grouped according to their corresponding BAM value. All coefficients using the same BAM are grouped together into a bin and normalized to be in the range of 0 to 2**N-1, where N is the number of bits assigned by the BAM. For example, coefficients assigned a BAM of 3 BPP would be normalized to range from 0 to 7. These are the output levels. The output levels can be optimized by using statistical methods to distribute the coefficients throughout the bin. Each level within the bin would then ideally contain coefficients which are close enough in value to be adequately represented by an average.
One such optimization method is Max's algorithm, Max [5]. This is defined by

\[ X_i = \frac{(Y_i + Y_{i-1})}{2} \quad i = 2, \ldots, N \]

and

\[ \sum_{X_i} (X - Y_i) P(x) dx = 0, \quad i = 1, 2, \ldots, N-1 \]

where

- \( N \) = the number of quantization levels,
- \( X_i \) = end points of the \( N \) levels,
- \( Y_i \) = output level corresponding to each input range,

and

- \( P(x) \) = input amplitude probability density as defined by the histogram.

This algorithm is solved by iterative calculations, changing the choice of \( Y_1 \) until a solution is found. These are the output levels to be stored in the QLUTs. All coefficients are processed to create the QLUTs. To then access the correct one, the normalized coefficient is fit into one of the levels and the appropriate QLUT is addressed. This output is the value of the compressed image at that location. When this is done for all of the coefficients in all of the transform blocks, the compressed image is now complete and can be stored with an average of 1 BPP.
Decompression

The decompression requires the database information containing the SDMs, BAMs and the inverse quantization lookup tables (IQLUTs), which are formed when the QLUTs are being addressed. For each element in the compressed image there is an IQLUT value, which corresponds to the coefficient average value assigned to that output level during quantization.

In addition the decompression requires the AAC assignment for each block in the image. The flow of decompression is shown in Figure 2.

The AAC is extracted for each location in the compressed image. From this, BAM can be accessed. The level of the location is the value in the compressed image. Knowing the BAM value and this level, the proper IQLUT table can be accessed. The normalized DCT value is the value in the IQLUT. Inverse normalization can be done, using the SDMs, yielding an average DCT value.
Figure 2. Adaptive DCT decompression.
The DCT values can now be run through an inverse transform:

\[ I'(j,k) = C' \ast T(m,n) \ast C \]

where

\[ I'(j,k) = \text{the pixel intensity,} \]
\[ T(m.n) = \text{the transformed coefficients in position M,N} \]

and

\[ C \] is defined previously.

The result of the inverse DCT is the reconstructed image.
CHAPTER IV

RESULTS

The resultant images obtained from the 24 to 3 bits per pixel compression and reconstruction are shown in Figure 3. The upper left image is the original image. Upper right is the image with 16 X 16 transform block sizes, retaining 8 X 8 coefficients per block. The lower left image was obtained with a block size of 8 X 8 pixels, 8 X 8 coefficients per block retained, and the lower right used a block size of 4 X 4 and retained 2 X 2 coefficients per block. Better results are obtained when this technique is applied over the entire 512 by 512 image, rather than just 256 by 256 as in Figure 3. Time constraints made it difficult to do that large an image here.
Subjective Error Analysis

The upper right image in Figure 3 has the largest block size and the shortest processing time. The image blocks are noticeable. There are some color shifts between the blocks and some slight incorrect color.

The image with the 8 X 8 block size, which is lower left in Figure 3, is of poor quality due to the relatively few bits per coefficient. With 8 coefficients retained there is no reduction in data over the spatial domain and the bits assigned must be spread over the whole transformed image. The color is very good in this case and the picture streaks could perhaps be filtered out. When the 8 X 8 block size is used with 4 coefficients retained, the blocks are evident due to too few coefficients being retained.

The lower right image of Figure 3 has the smallest block size, but only retains 4 coefficients per block. The color shifts are very obvious and incorrect color is very evident. The reduced number of coefficients causes unacceptable image degradation.
Figure 3. Results obtained from the adaptive DCT.
Objective Error Analysis

The error between the original image and the reconstructed image can be calculated by the mean-square error technique. The error at each pixel in the image is the absolute difference between the pixel intensities measured in red, green and blue. The absolute mean-square error over the image is calculated by:

\[ \text{ABS } E = \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} ((R(i,j)-R'(i,j))^2 + (G(i,j)-G'(i,j))^2 + (B(i,j)-B'(i,j))^2) / N \]

The relative error between pixels is calculated by:

\[ \text{REL } E = \sum_{j=0}^{N-1} \sum_{k=0}^{N-1} ((\text{ES}(i,j)-\text{ES}(i-1,j))^2 + (\text{ES}(i,j)-\text{ES}(i,j-1))^2) / N, \]

where \( N \) is the number of pixels.

The results obtained from the compression of the 16 X 16 blocks are a mean-squared error of 507 and a relative error of 304. For the 8 X 8 the mean-squared error is 652 and the relative error is 449. For the 4 X 4 in Figure 3 the mean-squared error is 7474 and the relative error is 1526.
CHAPTER V
CONCLUSIONS

The results obtained indicate that compressing to 3 BPP is too much compression for a high quality visual database. More bits per pixel are necessary for smooth, clear images. When too many coefficients are retained there are fewer bits per coefficient and the results are very blurred edges and streaks through the image. When too few are retained there are prominent color shifts between blocks and incorrect color within blocks. The blocks become very evident. The results obtained in the 16 X 16 with 256 coefficients per block would be sufficient perhaps for background in a simulator system with a highly detailed cut-out where the pilot is directly looking. This area of high resolution would have to be compressed to greater than 3 BPP.

Ideally, a large collection of images would be used when generating the database for this technique. The SDM,
QLUT and BAM assignment criteria would then be based on transform block comparisons between a larger variety of image information per adaptive assignment code. This could lead to a more accurate statistical data pool for the use of future images. New image transform blocks would be assigned an AAC and would then access the proper BAMs, QLUTS and SDMs already available. The process would be much quicker and the results should be better.

The adaptive technique could be applied over a whole database of image sequences. The same technique of comparing relative activity of blocks within an image can be applied to comparing activity between image frames in the database. Images that are relatively inactive may not need the overall average of 3 BPP, while very busy images may fare better with a higher average of bits per pixel. A classification system could be set up for classifying images by comparing the activity of images in the database. A coding scheme similar to the AAC can be used to assign a maximum number of bits per pixel to each image, with the overall database average being 3 BPP.

By redistributing the available bits over the entire database and then redistributing within each image, more accurate results can be obtained without affecting the ultimate goal of minimal storage.

The quantization is an essential part of the adaptivity. The data must be quantized as efficiently as
possible without degrading the results too severely. Due to
time limitations, an optimal quantization scheme was not
achieved, but one such as in Max [5] should be very
effective. The method used uniformly groups values within a
bin into the levels of the bin. Each level ends up with
approximately the same number of entries. Max's method
takes into account the values being grouped together, as
well as the probability of certain ranges of values
occurring for a particular bin. With this knowledge the
distribution of coefficients between the levels of a bin
could be optimized.

There is room for improving the adaptivity. For a
visual flight simulator, desiring high resolution for
tactical missions training the image must be very high
quality. The adaptive DCT method requires large amounts of
computer time and space to implement when setting up the
database. After a database is generated however the process
should be considerably simplified.
APPENDIX

PROGRAM COMPRESS
C THIS PROGRAM USES AN ADAPTIVE DCT METHOD TO COMPRESS AN IMAGE
C
IMPLICIT NONE
INCLUDE 'COLOR.INC'
C
INTEGER I,J,K,M,K,N,UNIT,N_ROWS,N_COLS,CONSTANT,L
INTEGER R,C,PIXEL,IOS,MINR,MAXR,MINB,MAXB,MING,MAXG
INTEGER IMAGE_SIZE
BYTE BITE
EQUIVALENCE (BITE,PIXEL)
C
READ THE IMAGE INTO THE RED, GREEN AND BLUE COLOR ARRAYS
C
INITIAL FLG=0
DBGFLG=0
PRINT*,' DO YOU WANT DIAGNOSTICS TURNED ON l=YES 0=NO'
READ*,DBGFLG
DISTORT_AAC=1024
DISTORT_BAM=1
C OPEN QUANTIZE ARRAY
OPEN(UNIT=12,NAME='IQLUT.DAT',TYPE='UNKNOWN',
    FORM='FORMATTED')
OPEN(UNIT=14,NAME='CSCENE1.DAT',TYPE='UNKNOWN',
    FORM='UNFORMATTED')
OPEN(UNIT=15,NAME='BAMFILE.DAT',TYPE='UNKNOWN',
    FORM='FORMATTED')
OPEN(UNIT=16,NAME='SDMFILE.DAT',TYPE='UNKNOWN',
    FORM='FORMATTED')
OPEN(UNIT=17,NAME='AACFILE.DAT',TYPE='UNKNOWN',
    FORM='FORMATTED')
PRINT*, ' IMAGE SIZE= '
READ*,IMAGE_SIZE
C READ IN 512X512 ARRAY
OPEN(UNIT=10,
    NAME='BIGSCSN.DAT',
    TYPE='OLD',FORM='UNFORMATTED',ERR=100)
DO I=0,IMAGE_SIZE-1
READ(10,ERR=101)(RED_IMAGE(I,J),J=0,IMAGE_SIZE-1)
READ(10,ERR=102)(GRE_IMAGE(I,J),J=0,IMAGE_SIZE-1)
READ(10,ERR=103)(BLU_IMAGE(I,J),J=0,IMAGE_SIZE-1)
ENDDO
CLOSE(UNIT=10)
C SET UP VARIABLE PARAMETERS TO BE PASSED IN COMMON
IF(INITIAL_FLG.EQ.0) THEN
50 PRINT*, ' BLOCK SIZE = ',
      ' 4X4,8X8,16X16, ENTER 4,8 OR 16'
READ(5,*,ERR=50) BLK_SIZE
N_ROWS=BLK_SIZE
N_COLS=BLK_SIZE
NUM_BLKS=IMAGE_SIZE/BLK_SIZE
ENDIF
C RED, GREEN, BLUE LOOP
C
DO K=1,3
   IF(K.EQ.1) COLOR=1
   IF(K.EQ.2) COLOR=2
   IF(K.EQ.3) COLOR=3
   DO J=0,IMAGE_SIZE-1
      DO I=0,IMAGE_SIZE-1
         IF(K.EQ.1) IMAGE(I,J)=RED_IMAGE(I,J)
         IF(K.EQ.2) IMAGE(I,J)=GREEN_IMAGE(I,J)
         IF(K.EQ.3) IMAGE(I,J)=BLUE_IMAGE(I,J)
      END DO
   END DO
C CALCULATE THE DCT
   CALL CALC_DCT
C CALCULATE THE ENERGY OF EACH BLOCK
   CALL CALC_ENERGY
C CALCULATE THE ADAPTIVE ASSIGNMENT CODE
   CALL CALC_AAC
C CALCULATE THE STANDARD DEVIATION MATRICES
   CALL CALC_SD
C CALCULATE THE BIT ASSIGNMENT MATRICES
   CALL CALC_BAM
C NORMALIZE THE COEFFICIENT
   CALL NORMALIZE
C CALL QUANTIZE
   CALL QUANTIZE
C
DO NEXT COLOR IMAGE= END OF K LOOP, RESET INITIAL FLAG
   INITIAL_FLG=1
C WRITE COMPRESSED IMAGE TO FILE
   N=NUM_BLKS*N_COEF_ROW
   DO I=0,N-1
      WRITE(14)(IMAGE(J,I),J=0,N-1)
   ENDDO
C
ENDDO ! END OF K LOOP
C
PRINT*, ' OPENED AND WROTE C-IMAGE '
CLOSE(UNIT=FUNIT)
CALL LIB$FREE_LUN(FUNIT)
CLOSE(12)
CLOSE(14)
CLOSE(15)
CLOSE(16)
CLOSE(17)
C STOP
C 100 PRINT*, ' ERROR IN OPENING IMAGE FILE IOSTAT = ',IOSTAT
   STOP
101 PRINT*, ' ERROR READING RED FILE IOSTAT = ',IOSTAT
   STOP
102 PRINT*, ' ERROR READING GREEN FILE IOSTAT = ',IOSTAT
   STOP
103 PRINT*, ' ERROR READING BLUE FILE IOSTAT = ',IOSTAT
C END
! END PROGRAM
C DO NEXT COLOR IMAGE- END OF K LOOP, RESET INITIAL FLAG
  INITIAL_FLG=1
C WRITE COMPRESSED IMAGE TO FILE
  N=NUM_BLKS*N_COEF_ROW
  DO I=0,N-1
    WRITE(14)(IMAGE(J,I),J=0,N-1)
  ENDDO
C ENDDO !END OF K LOOP
C
C PRINT*, 'OPENED AND WROTE C-IMAGE'
C CLOSE(UNIT=FUNIT)
C CALL LIB$FREE_LUN(FUNIT)
C CLOSE(12)
C CLOSE(14)
C CLOSE(15)
C CLOSE(16)
C CLOSE(17)
C
C STOP
C
C 100 PRINT*, 'ERROR IN OPENING IMAGE FILE' IOSTAT = ',',IOS
C STOP
C 101 PRINT*, 'ERROR READING RED FILE' IOSTAT = ',',IOS
C STOP
C 102 PRINT*, 'ERROR READING GREEN FILE' IOSTAT = ',',IOS
C STOP
C 103 PRINT*, 'ERROR READING BLUE FILE' IOSTAT = ',',IOS
C END
C ! END PROGRAM
SUBROUTINE CALC_ENERGY

THIS ROUTINE CALCULATES THE ENERGY PER TRANSFORM BLOCK WITHIN AN IMAGE MEASURED AS THE VARIANCE BETWEEN PIXELS

IMPLICIT NONE
INCLUDE 'COLOR.INC'

INTEGER C,R,R_BLK_NUM,C_BLK_NUM,X,Y,J,K,I
REAL TEMP_AVG,DEV(16,16),TEMP_SD,AVG,MIN,MAX

CALC ENERGY PER TRANSFORM BLOCK
MIN=99999
MAX=-99999
DO I=1,NUM_BLKS
DO J=1,NUM_BLKS
ENERGY(I,J)=0
ENDDO
ENDDO
DO R_BLK_NUM = 1,NUM_BLKS
DO C_BLK_NUM = 1,NUM_BLKS
X = (R_BLK_NUM-1)*BLK_SIZE
Y = (C_BLK_NUM-1)*BLK_SIZE

CALC THE AVG
TEMP_SD=0.
TEMP_AVG=0.
DO J = X,X+BLK_SIZE-1
DO K = Y,Y+BLK_SIZE-1
   TEMP_AVG = FLOAT(IMAGE(K,J)) + TEMP_AVG
ENDDO
ENDDO
AVG = TEMP_AVG/FLOAT(BLK_SIZE*BLK_SIZE)

FIND EACH DEVIATION
DO J = X,X+BLK_SIZE-1
DO K = Y,Y+BLK_SIZE-1
   DEV(K-Y+1,J-X+1) = FLOAT(IMAGE(K,J)) - AVG
   IF(DBGFLG.EQ.3)PRINT*,I,DEV(K-Y+1,J-X+1)
   TEMP_SD = DEV(K-Y+1,J-X+1)*DEV(K-Y+1,J-X+1) + TEMP_SD
   IF(DBGFLG.EQ.3)PRINT*,I,TEMP_SD,TEMP_SD
ENDDO
ENDDO
CALC VAR
ENERGY(C_BLK_NUM,R_BLK_NUM)=TEMP_SD/(BLK_SIZE*BLK_SIZE)
IF(ENERGY(C_BLK_NUM,R_BLK_NUM).LT.5) THEN
   ENERGY(C_BLK_NUM,R_BLK_NUM)=5.
ENDIF
IF(DBGFLG.EQ.3)PRINT*,AVG,TEMP_SD,ENERGY(C_BLK_NUM,R_BLK_NUM)
ENDDO
ENDDO
FIND THE AVERAGE OF ALL THE BLOCKS
AVG = 0.0
DO R_Blk_Num = 1,Num_blks
   DO C_Blk_Num = 1,Num_blks
      AVG = AVG + ENERGY(C_Blk_Num, R_Blk_Num)
   ENDDO
ENDDO
AVG = AVG / FLOAT(Num_blks * Num_blks)
C
C FIND THE STANDARD DEVIATION OF ALL THE BLOCKS
C
TEMP_SD = 0
DO R_Blk_Num = 1,Num_blks
   DO C_Blk_Num = 1,Num_blks
      TEMP_SD = TEMP_SD + (ENERGY(C_Blk_Num, R_Blk_Num) - AVG)**2
   ENDDO
ENDDO
TEMP_SD = TEMP_SD / FLOAT(Num_blks * Num_blks)
C
RETURN
END
C
***************************************************************
**SUBROUTINE CALC_AAC**

**IMPLICIT** NONE

**INCLUDE** 'COLOR.INC'

**INTEGER** R_NUM, C_NUM, CNT, FUNIT, X, Y
**REAL** I, PREVI, DELTA, DISTORT_NOW

**REAL** F_BLK_SIZE, AAC_SUM, TEMP, RAAC(128, 128), PAAC_SUM, SAVE

**F_BLK_SIZE** = **FLOAT**(BLK_SIZE*BLK_SIZE)

CNT = 0
AAC_SUM = 0
PAAC_SUM = 0
PREVI = 11.0
I = 10.0
DELTA = 1.0
SAVE = DISTORT_AAC
DISTORT_NOW = DISTORT_AAC

**CONTINUE**

CNT = CNT + 1
AAC_SUM = AAC_SUM / NUM_BLKS**2
IF (CNT.EQ.1) PAAC_SUM = AAC_SUM
IF (CNT.LT.12) THEN
 IF (AAC_SUM.GT.4.) THEN
 TEMP = I
 I = I + DELTA
 IF (.NOT. (I.GT.PREVI.AND. TEMP.GT.PREVI)) THEN
 DELTA = DELTA / 2.
 I = PREVI + DELTA
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 GOTO 50
 ELSE IF (AAC_SUM.LT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I - DELTA
 IF (.NOT. (I.LT.PREVI.AND. TEMP.LT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.GT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I + DELTA
 IF (.NOT. (I.GT.PREVI.AND. TEMP.GT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.LT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I - DELTA
 IF (.NOT. (I.LT.PREVI.AND. TEMP.LT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.GT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I + DELTA
 IF (.NOT. (I.GT.PREVI.AND. TEMP.GT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.LT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I - DELTA
 IF (.NOT. (I.LT.PREVI.AND. TEMP.LT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.GT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I + DELTA
 IF (.NOT. (I.GT.PREVI.AND. TEMP.GT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.LT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I - DELTA
 IF (.NOT. (I.LT.PREVI.AND. TEMP.LT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.GT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I + DELTA
 IF (.NOT. (I.GT.PREVI.AND. TEMP.GT.PREVI)) THEN
 DELTA = DELTA / 2.
 ELSE
 PREVI = TEMP
 ENDIF
 IF (I.GT.12.) I = 12.
 DISTORT_NOW = 2.**I
 IF (DBGFLG.EQ.1) PRINT*, AAC_SUM, I, PREVI, DISTORT_NOW
 ELSE IF (AAC_SUM.LT.4.) THEN
 IF (AAC_SUM.GT.PAAC_SUM) THEN
 PAAC_SUM = AAC_SUM
 SAVE = DISTORT_NOW
 ENDIF
 TEMP = I
 I = I - DELTA
 IF (.NOT. (I.LT.PREVI.AND. TEMP.LT.PREVI)) THEN
 DELTA = DELTA / 2.
I=PREVI-DELTA
ELSE
ENDIF
IF(I.LT.1.) I=1.
DISTORT_NOW = 2.**I
IF(DBGFLG.EQ.1)PRINT*,AAC_SUM,I,PREVI,DISTORT_NOW
GOTO 50
ELSE
C THE AVG OF THE AVG BPP ASSIGNED BY THE AAC
C IS 1BPP OVER THE ENTIRE IMAGE
GOTO 101
ENDIF
ENDIF
IF(DBGFLG.EQ.20) THEN
PRINT*,' AAC EQUALITY FAILED TO CONVERGE SAVE =',SAVE
ENDIF
DISTORT_NOW=SAVE
DO R_NUM = 1,NUM_BLKS
  DO C_NUM = 1,NUM_BLKS
    TEMP=ENERGY(C_NUM,R_NUM)/2.0
    IF(TEMP.LT.0.0001) THEN
      RAAC(C_NUM,R_NUM)=0
      ELSE
        RAAC(C_NUM,R_NUM)=(ALOG(TEMP)/ALOG(2.0))
        $ -DISTORT_NOW/(F_BLK_SIZE)
    END IF
  END DO
END DO
C IF IT CONVERGES
101 CONTINUE
C
DO R_NUM=1,NUM_BLKS
  DO C_NUM=1,NUM_BLKS
    IF(RAAC(C_NUM,R_NUM).LT.1.0)THEN
      AAC(C_NUM,R_NUM)=1
      ELSEIF(RAAC(C_NUM,R_NUM).GE.9.0)THEN
        AAC(C_NUM,R_NUM)=S
      ELSE
        AAC(C_NUM,R_NUM)=INT(RAAC(C_NUM,R_NUM))
      END IF
    END DO
END DO
C WRITE THE AAC COMPARE DATA TO FILE IF RGBDONE
DO C_NUM=1,NUM_BLKS
  WRITE(17,25)(AAC(C_NUM,X),X=1,NUM_BLKS)
END DO
C
25 FORMAT(1X,<NUM_BLKS>I2)
C
C TABLE OF AVG BITS PER WORD FOR AACs
SET(1)=.375
SET(2)=.375
SET(3)=.6875
SET(4)=1.0
SET(5)=1.3125
SET(6)=1.625
SET(7)=1.9375
SET(8)=2.25
RETURN
END
SUBROUTINE CALC_SDM

IMPLICIT NONE
INCLUDE 'COLOR.INC'

INTEGER X,Y,R_NUM,C_NUM,M,N,X_LOC,Y_LOC,CODE,START
REAL TEMP(16,128), AVG, SQDEV
REAL TEMP_SUM(16,128), SD
INTEGER FUNIT, CNT(8)

DO FOR EACH AAC
  DO CODE=1,8
    CNT(CODE)=0
  ENDDO
  DO X=1,16
    DO Y=1,128
      TEMP(X,Y)=0
      TEMP_SUM(X,Y)=0
    ENDDO
  ENDDO
  DO CODE=1,8
    START = (CODE-1) * N_COEF_ROW
  ENDDO

DO FOR EACH XFORM BLOCK
  DO R_NUM = 1, NUM_BLKS
    DO C_NUM = 1, NUM_BLKS
      X = (R_NUM-1) * N_COEF_ROW
      Y = (C_NUM-1) * N_COEF_ROW
      USE COEFFICIENTS OF BLOCKS FOR SAME AAC TO CALCULATE SDM
      IF(AAC(C_NUM,R_NUM).EQ.CODE)THEN
        CNT(CODE)=CNT(CODE)+1
        IF(DBGFLG.EQ.1) PRINT*, 'CODE CNT ', CODE, CNT(CODE)
        X_LOC = 1
      ENDDO
    ENDDO
  ENDDO
  DO FOR EACH COEFF LOCATION
    DO N = X, N_COEF_ROW + (X-1)
      Y_LOC = 1
      DO M = Y, N_COEF_ROW + (Y-1)
        TEMP(Y_LOC,X_LOC+START)=DCT(M,N)+
        TEMP(Y_LOC,X_LOC+START)
        Y_LOC = Y_LOC + 1
      ENDDO
    X_LOC = X_LOC + 1
  ENDDO
ENDDO
ENDDO

ALL OF CODE X ARE DONE AND ADDED TO TEMP

DO R_NUM = 1, NUM_BLKS
  DO C_NUM = 1, NUM_BLKS
    X = (R_NUM-1) * N_COEF_ROW
\[ y = (c_{\text{num}}-1)^n_{\text{coef}} \text{row} \]

C EACH COEFFICIENT

\[
\text{IF}(\text{AAC}(c_{\text{num}}, r_{\text{num}}).\text{Eq}. \text{Code}) \Rightarrow
\]
\[ x_{\text{loc}} = 1 \]
\[ \text{DO} n = x, n_{\text{coef}} \text{row} + (x-1) \]
\[ y_{\text{loc}} = 1 \]
\[ \text{DO} m = y, n_{\text{coef}} \text{row} + (y-1) \]

\[
\text{IF}(\text{DBGFLG}.\text{Eq}. 1) \text{PRINT}*,', \text{TEMP}' , \text{TEMP}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) \]
\[ \text{AVG} = \text{TEMP}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) / \text{FLOAT}(\text{CNT}(\text{CODE})) \]

C TAKE CARE OF THE CASE OF ALL ZERO COEFFICIENTS

\[
\text{IF}(\text{ABS}(\text{AVG}).\text{LT}.0.000001) \Rightarrow
\]
\[ \text{ZERO}_\text{ARRAY}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) = 0 \]
\[ \text{ELSE} \]
\[ \text{ZERO}_\text{ARRAY}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) = 99 \]
\[ \text{ENDIF} \]

\[
\text{SQDEV} = (\text{DCT}(m, n) - \text{AVG})^2 \times 2
\]
\[ \text{TEMP}_{\text{SUM}}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) = \]
\[ \text{TEMP}_{\text{SUM}}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) + \text{SQDEV} \]
\[ y_{\text{loc}} = y_{\text{loc}} + 1 \]
\[ \text{ENDDO} \]
\[ x_{\text{loc}} = x_{\text{loc}} + 1 \]
\[ \text{ENDDO} \]
\[ \text{ENDIF} \]

C ENDDO

C TAKE RMS OF DEV

\[
\text{IF}(\text{CNT}(\text{CODE}).\text{NE}.0) \Rightarrow
\]
\[ \text{DO} y_{\text{loc}} = 1, n_{\text{coef}} \text{row} \]
\[ x_{\text{loc}} = 1, n_{\text{coef}} \text{row} \]
\[ \text{SD} = \text{SQRT}(\text{TEMP}_{\text{SUM}}(y_{\text{loc}}, x_{\text{loc}} + \text{start}) / \text{FLOAT}(\text{CNT}(\text{CODE}))) \]
\[ \text{IF}(\text{SD}.\text{GT}.0.1) \Rightarrow
\]
\[ \text{SDM}(y_{\text{loc}}, \text{start} + x_{\text{loc}}) = \text{SD} \]
\[ \text{ELSE} \]
\[ \text{SDM}(y_{\text{loc}}, \text{start} + x_{\text{loc}}) = 0 \]
\[ \text{ENDIF} \]
\[ \text{ENDDO} \]
\[ \text{ENDDO} \]
\[ \text{ELSE} \]
\[ \text{DO} y_{\text{loc}} = 1, n_{\text{coef}} \text{row} \]
\[ x_{\text{loc}} = 1, n_{\text{coef}} \text{row} \]
\[ \text{SDM}(y_{\text{loc}}, \text{start} + x_{\text{loc}}) = 0 \]
\[ \text{ENDDO} \]
\[ \text{ENDDO} \]
\[ \text{ENDIF} \]

C END OF THAT AAC CODE

C ENDDO

C WRITE TO DATAFILE IF RGB DONE

\[ \text{PRINT*},', \text{COLOR}',', \text{COLOR} \]

C \[ \text{DO CODE}=1,8 \]
\[ \text{DO} y=1, n_{\text{coef}} \text{row} \]
\[ x_{\text{loc}}=(\text{CODE}=1)^{n_{\text{coef}} \text{row}+1} \]
\[ \text{WRITE}(16,25)(\text{SDM}(y, x), x=x_{\text{loc}}, x_{\text{loc}}+n_{\text{coef}} \text{row}-1) \]
SUBROUTINE CALC_BAM

IMPLICIT NONE
INCLUDE 'COLOR.INC'

INTEGER CODE,X_LOC,Y_LOC,XX,CNT,FUNIT,X,Y
INTEGER INT,YY,NUM_DIS,END_X_LOC,END_Y_LOC
REAL BAM_SUM,TEMP,BAM_AVG,SAVE,BEST
REAL INITIAL,NBPBLK,DISTORT_NOW
LOGICAL POSSIBLE,SOLN

INITIAL=DISTORT_BAM

DO X_LOC=1,128
   DO Y_LOC=1,16
      BAM(Y_LOC,X_LOC)=0
   ENDDO
ENDDO

DO CODE = 1,8
   DISTORT_NOW=INITIAL
   SOLN=.FALSE.
   NBPBLK=SET(CODE)*N_COEF_ROW*N_COEF_ROW
   BEST=0
   CNT = 0
   SAVE=0
   XX = (CODE-1) * N_COEF_ROW + 1
   CONTINUE
   BAM_SUM=0
   BAM_AVG=0
   POSSIBLE=.FALSE.
   CNT = CNT + 1
   DO X_LOC = XX,XX+N_COEF_ROW-1
      DO Y_LOC = 1,N_COEF_ROW
         IF(SDM(Y_LOC,X_LOC).NE.0) THEN
            TEMP=ALOG(SDM(Y_LOC,X_LOC))/ALOG(2.0)
            BAM(Y_LOC,X_LOC)=INT(TEMP-DISTORT_NOW)
            IF(BAM(Y_LOC,X_LOC).GT.8) BAM(Y_LOC,X_LOC)=8
            IF(BAM(Y_LOC,X_LOC).LT.0) BAM(Y_LOC,X_LOC)=0
            POSSIBLE=.TRUE.
         ELSE
            C ASSIGN 0 BITS WHERE THERE ARE NO COEFFICIENTS EXCEPT 0'S
            IF(ZERO_ARRAY(Y_LOC,X_LOC).EQ.0) THEN
               BAM(Y_LOC,X_LOC)=0
            ELSE
               C ASSIGN 1 BIT WHERE THERE IS NO STANDARD DEVIATION
               BAM(Y_LOC,X_LOC)=1
            ENDIF
         ENDIF
      ENDDO
   ENDDO
END
BAM_SUM = BAM(Y_LOC, X_LOC) + BAM_SUM
ENDDO
ENDDO
IF(.NOT..POSSIBLE) goto 789
C
BAM_AVG=BAM_SUM/FLOAT(N_COEF_ROW**2)
C
IF(CNT.LT.50) THEN
  IF(BAM_SUM.LT.NBPBLK) THEN
    IF((NBPBLK-BAM_SUM).LT.1.0) GOTO 30
    IF(DISTORT_NOW.EQ.0) THEN
      CNT = 49
    ELSE
      DISTORT_NOW = DISTORT_NOW - .02
    ENDIF
  ELSE
    DISTORT_NOW = DISTORT_NOW + .02
    IF(DISTORT_NOW.GT.10.0) DISTORT_NOW = 10.0
    GOTO 50
  ENDIF
ELSE
  IF(DBGFLG.EQ.6) THEN
    PRINT*, 'BAM MATCH CODE = ', CODE
  ENDIF
  GOTO 30
ENDIF
C THEY ARE EQUAL SO RETURN
ENDIF
C
ELSE
C IF CNT > 50 FIX BITS
C
789 IF(DBGFLG.EQ.5)
  IF(DBGFLG.EQ.5)
    & PRINT*, 'BAM CALC FAILED TO CONVERGE CODE = ', CODE
C USING LAST BEST ASSIGNMENT (IF EXISTING) AND DISTRIBUTE
C REMAINING BITS
C RE-INITIALIZE BAM
DO X_LOC=XX, XX+N_COEF_ROW-1
  DO Y_LOC=1, N_COEF_ROW
    BAM(Y_LOC, X_LOC)=0
  ENDDO
ENDDO
C
IF(SOLN) THEN
  DISTORT_NOW=SAVE
C
DO X_LOC = XX, XX+N_COEF_ROW-1
  DO Y_LOC = 1, N_COEF_ROW
    IF(SDM(Y_LOC, X_LOC).NE.0) THEN
      TEMP=ALOG(SDM(Y_LOC, X_LOC))/ALOG(2.0)
`BAM(Y_LOC,X_LOC)=INT(TEMP-DISTORT_NOW)`  
`IF(BAM(Y_LOC,X_LOC).GT.8) BAM(Y_LOC,X_LOC)=8`  
`IF(BAM(Y_LOC,X_LOC).LT.0) BAM(Y_LOC,X_LOC)=0`  
`POSSIBLE=.TRUE.`  
`ELSE`  
`BAM(Y_LOC,X_LOC)=0`  
`ENDIF`  
`ENDDO`  

`C FIND OUT HOW MANY BITS ARE REMAINING`  
`NBPBLK=NBPBLK-BEST`  
`ENDIF`  

`C DO ASSIGNING OF BAM VALUES`  

`NUM_DIS=INT(NBPBLK)`  
`END_Y_LOC=0`  
`END_X_LOC=XX-1`  
`DO WHILE(NUM_DIS.GT.0)`  
`END_Y_LOC=END_Y_LOC+1`  
`END_X_LOC=END_X_LOC+1`  
`IF(END_X_LOC.GT.XX+N_COEF_ROW) END_X_LOC=XX`  
`IF(END_Y_LOC.GT.N_COEF_ROW) END_Y_LOC=1`  
`DO X_LOC=XX,END_X_LOC`  
`DO Y_LOC=1,END_Y_LOC`  
`IF(NUM_DIS.GT.0) THEN`  
`IF(BAM(Y_LOC,X_LOC).LT.0) THEN`  
`BAM(Y_LOC,X_LOC)=BAM(Y_LOC,X_LOC)+1`  
`NUM_DIS=NUM_DIS-1`  
`ENDIF`  
`ENDIF`  
`ENDDO`  
`ENDDO`  

`C END OF CODE LOOP`  

`C WRITE BAM DATA TO FILE WHEN ALL RGB ARE DONE`  

`PRINT*, 'COLOR ',COLOR`  
`DO CODE=1,8`  
`DO Y=1,N_COEF_ROW`  
`X_LOC=(CODE-1)*N_COEF_ROW+1`  
`WRITE(15,25)(BAM(Y,X),X=X_LOC,X_LOC+N_COEF_ROW-1)`  
`ENDDO`  

`RETURN`  
`END`
SUBROUTINE CALC_DCT

C THIS ROUTINE CALCULATES THE DISCRETE COSINE TRANSFORM
C FOR EACH TRANSFORM BLOCK IN THE IMAGE
C CALLED FOR EACH XFORM BLOCK

IMPLICIT NONE
INCLUDE 'COLOR.INC'

INTEGER J, K, M, N, R_BLK_NUM, C_BLK_NUM, X, Y, XX, YY
INTEGER P, Q, N_COEF
REAL C(0:511, 0:511), PI, R_COEF, SQRT
REAL FJ, FK, FN, RN, FREQ_SUM
REAL NORM

C COEFFICIENTS TO RETAIN
IF(INITIAL_FLAG.EQ.0) THEN
PRINT*, 'NUMBER OF COEFFICIENTS PER ROW'
READ(5, *, ERR=500) N_COEF_ROW
N_COEF_ROW=N_COEF_ROW
END IF

RN=FLOAT(BLK_SIZE)
PI=3.1415926
SCALE=0.70710678
NORM=FLOAT(4)/(RN*RN)

C CLEAR DCT ARRAY
DO N=0, NUM_BLK*NUM_COEF_ROW-1
  DO M=0, NUM_BLK*NUM_COEF_ROW-1
    DCT(M, N)=0
  ENDDO
ENDDO

DO R_BLK_NUM = 1, NUM_BLK
  IF(DBGFLG.EQ.2) PRINT*, ' R_BLK_NUM = ', R_BLK_NUM
  XX=(R_BLK_NUM-1)*N_COEF_ROW
  X=(R_BLK_NUM-1)*BLK_SIZE
  DO C_BLK_NUM = 1, NUM_BLK
    IF(DBGFLG.EQ.2) PRINT*, ' C_BLK_NUM = ', C_BLK_NUM
    YY=(C_BLK_NUM-1)*N_COEF_ROW
    FN=FLOAT(BLK_SIZE)
    PN=FN+1.0
    FM=FM+1.0
    FJ=1.0
    DO J=YY, N_COEF_ROW+YY-1
      C(J, M)=COS((2.0*FJ+1.0)*PI*FN)/(2.*RN)
      FJ=FJ+1.0
    ENDDO
    FK=1.0
    DO K=XX, X+BLK_SIZE-1
      FK=FK+1.0
      C(K, N)=COS((2.0*FK+1.0)*PI*FN)/(2.*RN)
    ENDDO
    DCT(M, N)=FLOAT(IMAGE(J, K))*C(J, M)*C(K, N)+DCT(M, N)
  ENDDO
ENDDO

C
ENDDO

C IF FIRST TERM CALC THE DC VALUE
  IF(M.EQ.YY) THEN
    DCT(M,N)=DCT(M,N) * E_SCALE
  ENDFI
  IF(N.EQ.XX) THEN
    DCT(M,N)=DCT(M,N) * E_SCALE
  ENDFI
ENDDO

C CALCULATED ALL OF THE COEFFICIENTS
ENDDO

C DONE FOR ALL BLOCKS
25    FORMAT(1X,2I5,F12.6)
RETURN
END

C******************************************
C SUBROUTINE NORMALIZE
C NORMALIZE EACH COEFFICIENT BY ITS CORRESPONDING SDM VALUE
C IMPLICIT NONE
INCLUDE 'COLOR.INC'
INTEGER X,Y,XX,Y_LOC,X_LOC,R_NUM,C_NUM,N,M
REAL NORM
INTEGER BIN
C EACH BLOCK
DO R_NUM = 1,NUM_BKKS
  DO C_NUM = 1,NUM_BKKS
    X = (R_NUM - 1) * N_COEF_ROW
    Y = (C_NUM - 1) * N_COEF_ROW
  ENDDO
ENDDO

C EACH COEFFICIENT
X_LOC=0
DO N = X,N_COEF_ROW + (X-1)
  X_LOC=X_LOC+1
  Y_LOC=0
  DO M = Y,N_COEF_ROW + (Y-1)
    Y_LOC=Y_LOC+1
    XX = (AAC(C_NUM,R_NUM)-1)*N_COEF_ROW
    IF(DBGFLG.EQ.44) THEN
      BIN=BAM(Y_LOC,XX+X_LOC)
      IF(BIN.EQ.0) THEN
        PRINT*, ' DCT SDM ', DCT(M,N), SDM(Y_LOC,XX+X_LOC)
     ENDIF
    ENDFI
  ENDDO
  NORM = SDM(Y_LOC,XX+X_LOC)
  DCT(M,N) = DCT(M,N) / NORM
ENDDO
ENDDO
ENDDO
C
RETURN
END

***************************************************
SUBROUTINE QUANTIZE

THIS ROUTINE IS USED TO TAKE ALL OF THE COEFFICIENTS ASSIGNED THE SAME NUMBER OF BITS AND CONSTRUCT A HISTORGRAM, PERFORM MAX'S ALGORITHM, AND ASSIGN THE QUANTIZATION LEVELS TO BE OUTPUT.

IMPLICIT NONE
INCLUDE 'COLOR.INC'

INTEGER CNT(0:8),BIN,R_NUM,C_NUM,X,Y,N,M
INTEGER I,J,LEVEL,II,STARTI
INTEGER XLOC,YLOC
REAL MIN(0:8),MAX(0:8),FACTOR
INTEGER LOC,LEVELS,DELTA,END_INDEX
REAL IQLUT(0:8,0:255)
REAL TEMP
INTEGER*2 K,L
INTEGER START(256)
REAL IQLUT AVG
LOGICAL SWITCH

PRINT*, 'ENTERING QUANTIZE'

DO BIN=0,8
  CNT(BIN)=0
  MAX(BIN)=-99999
  MIN(BIN)=99999
ENDDO

DO NUM=1,NUM_BLK
  DO I=0,8
    DO J=0,255
      IQLUT(I,J)=0
    ENDDO
  ENDDO

C IF(DBGFLG.EQ.69)
C & PRINT*,' BIG LOOP',NUM_BLK,BLK_SIZE,N_COEF_ROW
C

DO R_NUM=1,NUM_BLK
  DO C_NUM=1,NUM_BLK
    X=(R_NUM-1)*N_COEF_ROW
    Y=(C_NUM-1)*N_COEF_ROW
  ENDDO
ENDDO

COLLECT ALL NORMALIZED COEFS TO BE CODED WITH THE SAME NUM OF BITS PER PIXEL (AS PER BAM)

XLOC=0
DO N=X,N_COEF_ROW+(X-1)
  XLOC=XLOC+1
YLOC=0
DO M=Y,N_COEF_ROW+(Y-1)
  YLOC=YLOC+1
  LOC=(AAC(C_NUM,R_NUM)-1)*N_COEF_ROW+1
  BIN=BAM(YLOC,LOC+XLOC-1)
  CNT(BIN)=CNT(BIN)+1
  PTRM(BIN,CNT(BIN))=M
  PTRN(BIN,CNT(BIN))=N
ENDDO
ENDDO

FIND MAX AND MIN VALUE FOR EACH BIN CATEGORY
IF(DCT(M,N).LT.MIN(BIN))
  MIN(BIN)=DCT(M,N)
&
IF(DCT(M,N).GT.MAX(BIN))
  MAX(BIN)=DCT(M,N)
C
END N LOOP
END DO
C END K LOOP
ENDDO
C END C_NUM LOOP
ENDDO
C END R_NUM LOOP
ENDDO
C
PRINT*,' ENTERING SORT '
DO BIN=1,8
PRINT*,' SORTING BIN ',BIN
IF(CNT(BIN).GT.0.AND.MIN(BIN).NE.MAX(BIN)) THEN
SWITCH=.TRUE.
STARTI=1
DO WHILE(SWITCH)
SWITCH=.FALSE.
DO I=STARTI,CNT(BIN)-1
IF(DCT(PTRM(BIN,I),PTRN(BIN,I)).GT.
  DCT(PTRM(BIN,I+1),PTRN(BIN,I+1))) THEN
  M=PTRM(BIN,I)
  PTRM(BIN,I)=PTRM(BIN,I+1)
  PTRM(BIN,I+1)=M
  N=PTRN(BIN,I)
  PTRN(BIN,I)=PTRN(BIN,I+1)
  PTRN(BIN,I+1)=N
  IF(.NOT.SWITCH) STARTI=I-1
  IF(STARTI.LT.1) STARTI=1
  SWITCH=.TRUE.
ENDIF
ENDDO
ENDDO
ENDIF
ENDIF
ENDDO
ENDDO
C
PRINT*,' EXITING SORT '
C LOAD THE IQLUT VALUES FOR BIN 0
C
IF(DBGFLG.EQ.1000) WRITE(33,33)
33 FORMAT(' BIN 0 ',//,' DCT M N')
IF(CNT(0).GT.0)THEN
  DO I = 1,CNT(0)
    IQLUT_AVG =IQLUT_AVG + DCT(PTRM(0,I),PTRN(0,I))
  ENDDO
  IQLUT(0,0)=IQLUT_AVG/CNT(0)
  IMAGE(PTRM(0,I),PTRN(0,I))=0
  ENDDO
ELSE
  IQLUT(0,0)=0.
ENDIF
WRITE(12,329) IQLUT(0,0)
329 FORMAT(1X,F14.9)
C
C DETERMINE QLUT FOR BIT ASSIGNMENT
C FORM QLUTS
C
DO BIN=1,8
   IF(CNT(BIN).GT.0.AND.MAX(BIN).NE.MIN(BIN)) THEN
      LEVELS=2**BIN
      START(1)=1
      DELTA=NINT(FLOAT(CNT(BIN))/FLOAT(LEVELS))
      IF(DELTA.LT.1) DELTA=1
      DO I=2,LEVELS
         START(I)=DELTA+START(I-1)
      ENDDO
      DO I = 1, LEVELS
         IQLUT_AVG=0
         IF(START(I).LT.CNT(BIN)) THEN
            IF(I.EQ.LEVELS) THEN
               END_INDEX=CNT(BIN)
            ELSE
               END_INDEX=START(I+1)
            ENDIF
            DO J=START(I),END_INDEX
               IQLUT_AVG=IQLUT_AVG+DCT(PTRM{BIN,J},PTRN(BIN,J))
               IMAGE(PTRM(BIN,J),PTRN(BIN,J))=I-1
            ENDDO
            IQLUT(BIN,I-1)=IQLUT_AVG/FLOAT(END_INDEX-START(I)+1)
         ELSE
            IQLUT(BIN,I-1)=99.
         ENDIF
      ENDDO
   ELSEIF(MAX(BIN).EQ.MIN(BIN)) THEN
      DO J=1,CNT(BIN)
         IMAGE(PTRM(BIN,J),PTRN(BIN,J))=0
      ENDDO
      IQLUT(BIN,0)=MAX(BIN)
   ENDIF
   WRITE(12,29)(IQLUT(BIN,LEVEL),LEVEL=0,255)
29 FORMAT(1X,32(8(F14.9),//))
ENDDO
RETURN
END
PROGRAM DECOMP

C THIS ROUTINE IS USED TO DECOMPRESS THE IMAGE
C FROM THE ADAPTIVE DCT METHOD

IMPLICIT NONE
INCLUDE 'DECOMP.INC'

INTEGER*2 RED_BUF(0:511),GRE_BUF(0:511),BLU_BUF(0:511)
BYTE DC_RED_IMAGE(0:511),DC_GREEN_IMAGE(0:511)
BYTE DC_BLUE_IMAGE(0:511),BITE
REAL MAX(0:8),LEV(8),NORM,NORM_DCT,RNO
REAL SORT,INQLUT_ARRAY(0:8,0:255),SDM(16,128)
INTEGER LEVEL,C_BAM(16,128)
INTEGER*2 C_RED_IMAGE(0:511,0:511)
INTEGER AAC(128,128),COLOR
INTEGER*2 C_GREEN_IMAGE(0:511,0:511)
INTEGER*2 C_BLUE_IMAGE(0:511,0:511)
INTEGER BIN,XX,K,J,I,R_NUM,C_NUM,X,Y,N,M
INTEGER POS,FUNIT,IOS,CODE,IX,PXEL,XLOC,CONSTANT
INTEGER TEMPX,YLOC,IMAGE_SIZE
EQUIVALENCE (BITE,PIXEL)

C DEFINITION OF THE MAXIMUM VALUE POSSIBLE FOR EACH BIT
C ASSIGNMENT (0-8 BITS CORRESPONDS TO 0-255 LEVELS)

PRINT*, ' ENTER BLK SIZE (16,8,4)' 
READ*,BLK_SIZE
PRINT*, ' IMAGE SIZE ' 
READ*,IMAGE_SIZE

NUM_BKLS=IMAGE_SIZE/BLK_SIZE
PRINT*, ' ENTER NUM COEF PER BLOCK ' 
READ*,N_COEF_ROW

OPEN(UNIT=17,NAME='AACFILE.DAT',TYPE='UNKNOWN',
FORM='FORMATTED')
OPEN(UNIT=15,NAME='BAMFILE.DAT',TYPE='UNKNOWN',
FORM='FORMATTED')
OPEN(UNIT=16,NAME='SDMFILE.DAT',TYPE='UNKNOWN',
FORM='FORMATTED')

C OPEN COMPRESSED IMAGE FILE
OPEN(UNIT=14,NAME='CSCENE1.DAT',TYPE='UNKNOWN',
FORM='UNFORMATTED',RECL=128,IOSTAT=IOS,ERR=22)

444 FORMAT(1X,8I4)
N=NUM_BKLS*N_COEF_ROW
DO I=0,N-1
READ(14,ERR=23,IOSTAT=IOS)(C_RED_IMAGE(K,I),K=0,N-1)
WRITE(70,444)(C_RED_IMAGE(K,I),K=0,N-1)
ENDDO

DO I=0,N-1
READ(14,ERR=23,IOSTAT=IOS)(C_GREEN_IMAGE(K,I),K=0,N-1)
WRITE(70,444)(C_GREEN_IMAGE(K,I),K=0,N-1)
ENDDO

DO I=0,N-1
READ(14,ERR=23,IOSTAT=IOS)(C_BLUE_IMAGE(K,I),K=0,N-1)
WRITE(70,444)(C_BLUE_IMAGE(K,I),K=0,N-1)

ENDDO
C
C CLOSE FILE
CLOSE(UNIT=14)
C
C OPEN THE IQLUT FILE
OPEN(UNIT=12,NAME='IQLUT.DAT',TYPE='UNKNOWN',FORM='FORMATTED')
C
C PROCESS THE RED, GREEN AND BLUE IMAGE SEPARATELY
DO K=1,3
  IF(K.EQ.1)COLOR=1
  IF(K.EQ.2)COLOR=2
  IF(K.EQ.3)COLOR=3
  PRINT*, 'COLOR= ',COLOR
  DO J=0,NUM_BLKS*N_COEF_ROW-1
    DO I=0,NUM_BLKS*N_COEF_ROW-1
      IF(K.EQ.1) IMAGE(I,J)=C_RED_IMAGE(I,J)
      IF(K.EQ.2) IMAGE(I,J)=C_GREEN_IMAGE(I,J)
      IF(K.EQ.3) IMAGE(I,J)=C_BLUE_IMAGE(I,J)
    ENDDO
  ENDDO
ENDDO
C
C READ IN THE IQLUT ARRAY
READ(12,37) IQLUT_ARRAY(0,0)
FORMAT(1X,F14.9)
DO BIN=1,8
  PRINT*, 'BIN = ',BIN
  READ(12,28)(IQLUT_ARRAY(BIN,LEVEL),LEVEL=0,255)
FORMAT(1X,32(8(F14.9),//))
ENDDO
C
C READ IN AAC
DO C_NUM=1,NUM_BLKS
  READ(17,234)(AAC(C_NUM,R_NUM),R_NUM=1,NUM_BLKS)
ENDDO
C
C READ IN BAM
DO CODE=1,8
  XLOC=(CODE-1)*N_COEF_ROW+1
  DO Y = 1,N_COEF_ROW
    READ(15,235)(BAM(Y,X),X=XLOC,XLOC+N_COEF_ROW-1)
  ENDDO
ENDDO
C
C READ IN SDM
DO CODE=1,8
  XLOC=(CODE-1)*N_COEF_ROW+1
  DO Y = 1,N_COEF_ROW
    READ(16,236)(SDM(Y,X),X=XLOC,XLOC+N_COEF_ROW-1)
  ENDDO
ENDDO
C
C PROCESS EACH TRANSFORM BLOCK
DO R_NUM=1,NUM_BLKS
  X=(R_NUM-1)*N_COEF_ROW
  DO C_NUM=1,NUM_BLKS
    Y=(C_NUM-1)*N_COEF_ROW
    XLOC=0
    DO N=X,N_COEF_ROW+X-1
      IF(K.EQ.1) IMAGE(N)=C_RED_IMAGE(N)
      IF(K.EQ.2) IMAGE(N)=C_GREEN_IMAGE(N)
      IF(K.EQ.3) IMAGE(N)=C_BLUE_IMAGE(N)
    ENDDO
  ENDDO
ENDDO
C
C END
have an overhead file associated with each image containing the AAC array and IQlut array for the image, also have the Bam and SDM.

C INVERSE QUANTIZATION
   LEVEL=IMAGE(M,N)
   PRINT*,' LEVEL ',LEVEL

C DETERMINE BIT ASSIGNMENT
   TEMPX=(AAC(C_NUM,R_NUM)-1)*N_COEF_ROW
   BIN=BAM(YLOC,TEMPX+XLOC)

C CALCULATE THE NORMALIZED DCT COEFFICIENT
   NORM_DCT=IQlut_ARRAY(BIN,LEVEL)
   IF(NORM_DCT.EQ.99.0) THEN
      PRINT*,' BIN LEVEL =99 ',BIN,LEVEL
   ENDIF

C INVERSE NORMALIZATION
   NORM=SDM(YLOC,TEMPX+XLOC)
   IF(NORM.EQ.0) THEN
      DCT(M,N)=NORM_DCT
   ELSE
      DCT(M,N)=NORM*NORM_DCT
   ENDIF

ENDDO
ENDDO

C PERFORM THE INVERSE DCT
CALL CALC_IDCT

DO I=0,IMAGE SIZE-1
   DO J=0,IMAGE SIZE-1
      IF(K.EQ.1) THEN
         C_RED_IMAGE(I,J)=INT(IDCT(I,J))
      ELSEIF(K.EQ.2) THEN
         C_GREEN_IMAGE(I,J)=INT(IDCT(I,J))
      ELSEIF(K.EQ.3) THEN
         C_BLUE_IMAGE(I,J)=INT(IDCT(I,J))
      ENDIF
   END DO
ENDDO

C END OF K LOOP
ENDDO

C CLOSE THE IQlut ARRAY
CLOSE(UNIT=12)

C OPEN NEW COLOR IMAGE FILE
PRINT*,' ABOUT TO OPEN NEW FILE '

CALL LIB$GET LUN(FUNIT)
OPEN(UNIT=FUNIT,NAME='DCMTLEFT.SCN',TYPE='UNKNOWN', FORM='UNFORMATTED',DEFAULTFILE='.SCN', RECL=128,RECORDTYPE='FIXED',IOSTAT=IOS,ERR=100)
PRINT*,' OPENED DC FILE '
C CONVERT TO BYTE FORMAT FROM INTEGER
C
DO I=0,IMAGE_SIZE-1
  DO J=0,IMAGE_SIZE-1
    PIXEL=(C_RED_IMAGE(I,J))
    DC_RED_IMAGE(J)=BITE
    PIXEL=(C_GREEN_IMAGE(I,J))
    DC_GREEN_IMAGE(J)=BITE
    PIXEL=(C_BLUE_IMAGE(I,J))
    DC_BLUE_IMAGE(J)=BITE
  ENDDO
C
C WRITE IN ALTERNATING RGB
WRITE(FUNIT)(DC_RED_IMAGE(POS),&
  POS=0,IMAGE_SIZE-1)
WRITE(FUNIT)(DC_GREEN_IMAGE(POS),&
  POS=0,IMAGE_SIZE-1)
WRITE(FUNIT)(DC_BLUE_IMAGE(POS),&
  POS=0,IMAGE_SIZE-1)
C
CLOSE(UNIT=FUNIT)
CALL LIBS$FREE_LUN(FUNIT)
C
STOP
22 PRINT*,', ERROR OPEN FILE -C IMAGE IOSTAT=', IOS
STOP
23 PRINT*,', ERROR READING C IMAGE IOSTAT=', IOS
STOP
100 PRINT*,', ERROR OPEN DC IMAGE IOSTAT=', IOS
STOP
101 PRINT*,', ERROR WRITING DC IMAGE IOSTAT=', IOS
STOP
C
END PROGRAM
C
*****************************************************************************
C
SUBROUTINE CALC_IDCT
C
THIS SUBROUTINE CALCULATES THE INVERSE DCT FOR THE
DECOMPRESSION
C
IMPLICIT NONE
INCLUDE 'DECOMP.INC'
INTEGER J,K,M,N,R_NUM,C_NUM,X,Y,XX,YY,I
REAL FJ,FK,FM,FN,SQRT,PI,RN,C(0:511,0:511)
REAL SUM,FREQ,E_SCALE
C
DO J=0,BLK_SIZE*NNUM_BLKS-1
  DO I=0,BLK_SIZE*NNUM_BLKS-1
    IDCT(I,J)=0
  ENDDO
ENDDO
C
PI=3.1415926
RN=FLOAT(BLK_SIZE)
E_SCALE=.70710678
C
DO R_NUM=1,NUM_BLKS
X=(R_NUM-1)*BLK_SIZE
XX=(R_NUM-1)*N_COEF_ROW
DO C_NUM=1,NUM_BLKS
  Y=(C_NUM-1)*BLK_SIZE
  YY=(C_NUM-1)*N_COEF_ROW
  FK=-1.0
  DO K=X,BLK_SIZE+X-1
    FK=FK+1.0
    FJ=-1.0
    DO J=Y,BLK_SIZE+Y-1
      SUM=0.0
      FJ=FJ+1.0
      FM=-1.0
      DO M=YY,YY+N_COEF_ROW-1
        FM=FM+1.0
        C(J,M)=COS((2.0*FJ+1.0)*PI*FM/(2.*RN))
      ENDDO
      FN=FN+1.0
      DO N=XX,XX+N_COEF_ROW-1
        FN=FN+1.0
        C(K,N)=COS((2.0*FK+1.0)*PI*FN/(2.*RN))
      ENDDO
    ENDDO
  ENDDO
END

FREQ=DCT(M,N)
IF(M.EQ.YY) THEN
  FREQ=FREQ*E_SCALE
ENDIF
IF(N.EQ.XX) THEN
  FREQ=FREQ*E_SCALE
ENDIF

SUM=SUM+FREQ*C(J,M)*C(K,N)
ENDDO
ENDDO

PRINT*, ' SUM ', SUM
IF(SUM.LT.0) SUM=0
IDCT(J,K)=SUM
END

END OF LOOP THRU COEFFICIENTS
ENDDO
ENDDO

END OF THE PIXELS FOR THE XFORM BLOCK
ENDDO
ENDDO

END OF BLOCKS
PRINT*, ' LEAVING IDCT '

RETURN

END
REFERENCES


