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(54) Title: EFFICIENT DOWN-SCALING OF DCT COMPRESSED IMAGES

→ Multiplication by 1/sqrt(2)
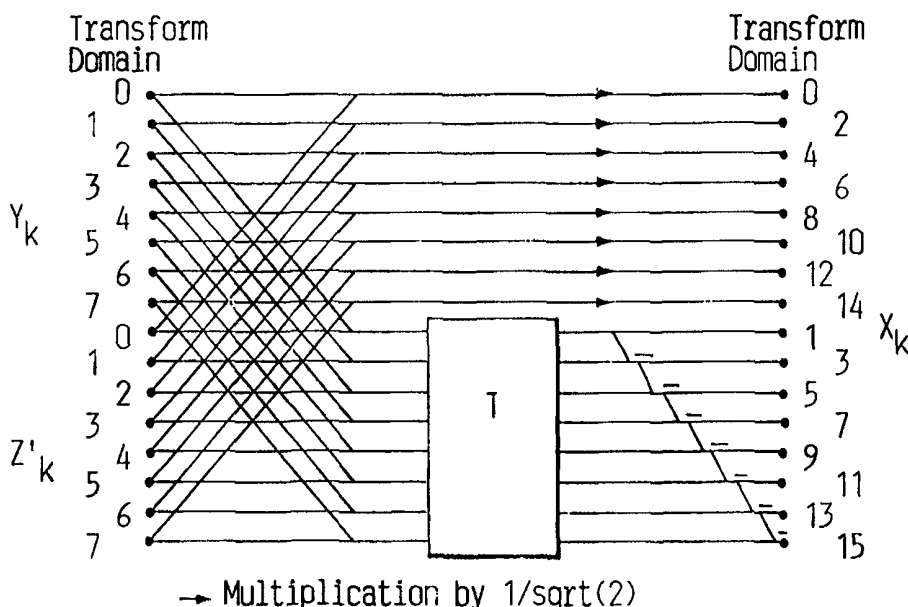
(57) Abstract

In a method and a device for calculation of the Discrete Cosine Transform (DCT) only the DCT coefficients representing the first half and the second half of an original sequence are required for obtaining the DCT for the entire original sequence. The device and the method are therefore very useful when calculations of DCTs of a certain length are supported by hardware and/or software, and when DCTs of other sizes are desired. Areas of application are for example still image and video transcoding, as well as scalable image and/or video coding and decoding.

EFFICIENT DOWN-SCALING OF DCT COMPRESSED IMAGES

TECHNICAL FIELD

The present invention relates to a method and a device for
scaling DCT compressed images.

BACKGROUND OF THE INVENTION AND PRIOR ART

The emergence of the compression standards JPEG, MPEG, H.26x
has enabled many consumer and business multimedia
applications, where the multimedia content is disseminated in
its compressed form. However, many applications require
processing of the multimedia content prior to presentation. A
very frequent process is that of down-sampling (down-scaling,
down-sizing) the compressed image.

Thus, in applications, such as image and video browsing, it
may be sufficient to deliver a lower resolution image or
video to the user. Based on user's input, the media server
could then provide the higher resolution image or video
sequence.

Also, composting several MPEG video sources into a single
displayed stream is important for MPEG video applications as
for example advanced multimedia terminals, interactive
network video and multi-point video conferencing. Composting
video directly in the compressed domain reduces computational
complexity by processing less data and avoiding the
conversion process back and forth between the compressed and
the uncompressed data formats. In compression standards
(MPEG, H.26x), compression is computationally 3 to 4 times
more expensive than decompression. Compressed domain based
down-sampling can be used to implement an efficient picture-
in-picture system for MPEG compressed video and can result in
significant savings.

Furthermore, efficient transcoding should be able to cope
with different quality of services in the case of multi-point
communications over POTS, ISDN, and ADSL lines. A HDTV down

conversion decoder can decode the Grand Alliance HDTV
bitstreams and display them on SDTV or NTSC monitors.

Conventional techniques for down-scaling rely on
decompressing the bitstreams first and then applying the
desired processing function (re-compression).

The down-sampling of a still image in the spatial domain
consists of two steps. First the image is filtered by an
anti-aliasing low pass filter and then it is sub-sampled by a
desired factor in each dimension. For a DCT-compressed image,
the above method implies that the compressed and quantised
image has to be recovered first into the spatial domain by
inverse DCT (IDCT or DCT^{-1}) and then undergo the procedure of
filtering and down-sampling as illustrated in Fig 1a.

A direct approach would be to work in the compressed domain,
where both operations of filtering and down-sampling are
combined in the DCT domain. This could be done by cutting off
DCT coefficients of high frequencies and using the IDCT with
a smaller number of coefficients to reconstruct the reduced
resolution image. For example, one could use the 4x4
coefficients out of the 8x8 and perform the IDCT on these
coefficients in order to reduce the resolution by a factor of
2 in each dimension as illustrated in Fig. 1b. This technique
does not result in significant compression gains and requires
encoders and decoders to be able to handle 4x4 DCTs and
IDCTs. It also requires run-length coding schemes to be
optimised for the 4x4 case. Furthermore, this method results
in significant amount of blocking effects and distortions,
due to the poor approximations introduced by simply
discarding higher order coefficients.

This technique would be more useful if 16x16 DCT blocks was
used and were 8x8 DCT coefficients were kept in order to
obtain the down-sampled. However, most image and video
compression standards, like JPEG, H.26x, and MPEG, segment
the images into rectangular blocks of size 8x8 pixels and
apply the DCT on these blocks. Therefore, only 8x8 DCTs are

available. One way to compute the 16x16 DCT coefficients is
to apply inverse DCT in each of the 8x8 blocks and
reconstruct the image.

Then the DCT in blocks of size 16x16 could be applied and the
8x8 out of the 16x16 DCTs coefficients of each block could be
kept. This would lead to a complete decoding (performing 8x8
IDCTs) and re-transforming by 16x16 DCTs, something that
would require 16x16 DCT hardware or software.

However, if one could compute the 8x8 out of the 16x16 DCT
coefficients by using only 8x8 transformations, then this
method would be faster and it would perform better than the
one that uses the 4x4 out of the 8x8. This would also mean
that by avoiding the computation of DCTs of size 16x16, the
memory requirements could also be reduced as illustrated in
Fig. 1c.

Furthermore, in the international patent application
PCT/SE98/00448 a method and a device for encoding/decoding
DCT compressed images in the frequency domain are described,
and which application is hereby is enclosed herein by
reference.

SUMMARY
It is an object of the present invention to provide a more
efficient encoding/decoding/transcoding algorithm for
obtaining the DCT coefficients of a block from DCT
coefficients of the four adjacent blocks than the algorithms
described in the above international application
PCT/SE98/00448.

This object is obtained by a device and a method as set out
in the appended claims.

Thus, by using the coding/decoding algorithm as described
herein a very efficient computation of an NxN point DCT given
the N/2xN/2 DCT coefficients for four adjacent blocks is

achieved. All the operations are performed in the transform
domain, so called transform domain manipulation (TDM).

BRIEF DESCRIPTION OF THE DRAWINGS
The present invention will now be described in more detail
and with reference to the accompanying drawings, in which:
-   Figs. 1a - 1c illustrates different techniques of down
    scaling an image according to the prior art.
-   Fig. 2 illustrates the operation of combining four
    adjacent DCT blocks.
-   Figs. 3a and 3b show flow graphs for the calculation of an
    N point DCT, by the two adjacent N/2 DCTs.
-   Fig. 4 is a block diagram illustrating a matrix
    multiplication.
-   Figs. 5a and 5b illustrates the down sizing of four
    adjacent DCT blocks.

DETAILED DESCRIPTION
In order to simplify the notation and discussion the 1-D
down-sampling analysis is presented. Because the DCT is
separable, all results extend to the 2-D case by simply
applying the properties in each of the two dimensions
consecutively.

Assume that the DCT coefficients Y_k and Z_k, ($k = 0,1,...,(N/2)-1$),
of two consecutive data sequences y_n and z_n, ($n = 0,1,...,(N/2)-1$),
are given, where $N = 2^m$. The problem to be addressed is the
efficient computation of X_k, ($k = 0,1,...,N-1$) directly in the DCT
domain, given Y_k and Z_k, where X_k are the DCT coefficients of
x_n, ($n = 0,1,...,N-1$), the sequence generated by the concatenation
of y_n and z_n. The normalised forward DCT (DCT-II) and inverse
DCT (IDCT) of the length-N sequence x_n are given by the
following equations:

$$X_k = \sqrt{\frac{2}{N}} \varepsilon_k \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)k\pi}{2N}, \quad k = 0,1,...,N-1 \text{ and}$$

$$x_n = \sqrt{\frac{2}{N}} \sum_{k=0}^{N-1} \varepsilon_k X_k \cos\frac{(2n+1)k\pi}{2N}, \quad n = 0,1,...,N-1$$

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where $\varepsilon_k = 1/\sqrt{2}$ *for* $k = 0$ and $\varepsilon_k = 1$ *for* $k \neq 0$. Notice that $\varepsilon_{2k} = \varepsilon_k$ and $\varepsilon_{2k+1} = 1$.

The normalised DCT and IDCT for the length- (N/2) sequences y_n and z_n are given by similar expressions, where in this case N is substituted by N/2.

The computation is performed separately for the even- and the odd-indexed coefficients.

i. Even-indexed coefficients

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2k\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]\kappa\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}\left[Y_k + (-1)^k Z_k\right] = \sqrt{\frac{1}{2}}\left[Y_k + Z'_k\right] \quad k = 0,1,\dots,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\dots,(N/2)-1$.

ii. Odd-indexed coefficients

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}\text{or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1},$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,\dots,(N/2)-1$ and

$$= \left\{\sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}$$

r_n is a length-(N/2) DCT of the length-(N/2) IDCT of (Y_l-Z_l') multiplied by *2cos(2n+1)π/2N*. The flow graph of the proposed algorithm for the case of the concatenation of two 8-point

adjacent coefficient sequences (i.e. N=16), is depicted in
Fig. 3a. Down-sampling by a factor of 2 implies that only
coefficients 0, 2, 4, 6, 1, 3, 5, 7 have to be calculated.

The calculation of the odd-indexed coefficients could be
further simplified if the processes of DCT^{-1}, DCT and the
multiplications were substituted by a matrix multiplication
as shown in Fig. 3b. A block diagram of the steps needed for
these calculations is illustrated in Fig 4.

In the special case of N=16 that is under consideration, we
have:

$G=Y_1-Z_1'$ is a column vector of length 8 each element of which
equals to the difference of the corresponding input DCT
coefficients.

$g=C^{-1}\cdot G$ is a column vector of length 8 corresponding to the
IDCT of G, where $C^{-1}= C^T$ (C given below).

$r=E\cdot g$ is a column vector of length 8 each element of which is
the product of g by $2cos(2n+1)\ \pi/2N$, where n=0,1,...,7 and
N=16. E is a diagonal matrix and is given by E=2
diag{cos$(\pi/32)$, cos$(3\pi/32)$, cos$(5\pi/32)$, cos$(7\pi/32)$,
cos$(9\pi/32)$, cos$(11\pi/32)$, cos$(13\pi/32)$, cos$(15\pi/32)$}.

$\underline{R}=C\cdot r$ is a column vector of length 8 corresponding to the DCT
of r, where

$$C=\sqrt{\frac{2}{N/2}}\begin{bmatrix} \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} \\ \cos(\theta) & \cos(3\theta) & \cos(5\theta) & \cos(7\theta) & \cos(9\theta) & \cos(11\theta) & \cos(13\theta) & \cos(15\theta) \\ \cos(2\theta) & \cos(6\theta) & \cos(10\theta) & \cos(14\theta) & \cos(18\theta) & \cos(22\theta) & \cos(26\theta) & \cos(30\theta) \\ \cos(3\theta) & \cos(9\theta) & \cos(15\theta) & \cos(21\theta) & \cos(27\theta) & \cos(33\theta) & \cos(39\theta) & \cos(45\theta) \\ \cos(4\theta) & \cos(12\theta) & \cos(20\theta) & \cos(28\theta) & \cos(36\theta) & \cos(44\theta) & \cos(52\theta) & \cos(60\theta) \\ \cos(5\theta) & \cos(15\theta) & \cos(25\theta) & \cos(35\theta) & \cos(45\theta) & \cos(55\theta) & \cos(65\theta) & \cos(75\theta) \\ \cos(6\theta) & \cos(18\theta) & \cos(30\theta) & \cos(42\theta) & \cos(54\theta) & \cos(66\theta) & \cos(78\theta) & \cos(90\theta) \\ \cos(7\theta) & \cos(21\theta) & \cos(35\theta) & \cos(49\theta) & \cos(63\theta) & \cos(77\theta) & \cos(91\theta) & \cos(105\theta) \end{bmatrix}$$

and $\theta=\pi/N$, N=16.

$R = P \cdot \underline{R}$ is a column vector of length 8 each element of which is the product of R by $\sqrt{1/2}$, except for the first element that is multiplied by ½, i.e. matrix P equals to: $P = \text{diag}\{$½, $\sqrt{1/2}$, $\sqrt{1/2}$, $\sqrt{1/2}$, $\sqrt{1/2}$, $\sqrt{1/2}$, $\sqrt{1/2}$, $\sqrt{1/2}$ $\}$.

Taking into account all the above given equations, R is expressed as follows:

$R = P \cdot (C \cdot (E \cdot (C^{-1} \cdot G))) = P \cdot C \cdot E \cdot C^{-1} \cdot G$ or $R = T \cdot G$ where $T = P \cdot C \cdot E \cdot C^{-1}$. Note that matrix $C \cdot E \cdot C^{-1}$ is symmetric.
The multiplication of these 8x8 matrices results to

$$T = \begin{bmatrix} 0.6376 & 0.2986 & -0.0585 & 0.0241 & -0.0125 & 0.0071 & -0.0039 & 0.0018 \\ 0.4223 & 0.8433 & 0.3227 & -0.0710 & 0.0311 & -0.0164 & 0.0088 & -0.0039 \\ -0.0827 & 0.3227 & 0.8893 & 0.3057 & -0.0624 & 0.0259 & -0.0125 & 0.0053 \\ 0.0341 & -0.0710 & 0.3057 & 0.8978 & 0.3004 & -0.0585 & 0.0223 & -0.0086 \\ -0.0177 & 0.0311 & -0.0624 & 0.3004 & 0.9018 & 0.2969 & -0.0546 & 0.0170 \\ 0.0100 & -0.0164 & 0.0259 & -0.0585 & 0.2969 & 0.9057 & 0.2916 & -0.0460 \\ -0.0056 & 0.0088 & -0.0125 & 0.0223 & -0.0546 & 0.2916 & 0.9143 & 0.2745 \\ 0.0025 & -0.0039 & 0.0053 & -0.0086 & 0.0170 & -0.0460 & 0.2745 & 0.9603 \end{bmatrix}$$

as is shown below.

Thus, in the general case of down-scaling two concatenated N/2 DCT coefficient sequences into one N/2 coefficient sequence:

$T = P \cdot C \cdot E \cdot C^{-1}$
  where
$P = \text{diag}\{$½, $\sqrt{1/2}$, $\sqrt{1/2}$,..$\}$

$E = 2 \text{diag}\{ \cos\dfrac{(2n+1)\pi}{2N} \}$

$C = \sqrt{\dfrac{2}{N/2}} \{ \varepsilon_i \cos\dfrac{(2n+1)k\pi}{N} \}$, n,k=0,1,..,(N/2)-1

All matrices are of size N/2xN/2.

In the special case of N=16 the above given matrices become:

$a = \sqrt{1/2}$, $\theta = \pi / N$

$$P = \begin{bmatrix} .5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a \end{bmatrix}$$

$$E = 2 \begin{bmatrix} \cos(\theta/2) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \cos(3\theta/2) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \cos(5\theta/2) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos(7\theta/2) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \cos(9\theta/2) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \cos(\theta/2) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \cos(13\theta/2) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \cos(15\theta/2) \end{bmatrix}$$

$$C = \sqrt{\frac{2}{N/2}} \begin{bmatrix} \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} & \sqrt{1/2} \\ \cos(\theta) & \cos(3\theta) & \cos(5\theta) & \cos(7\theta) & \cos(9\theta) & \cos(11\theta) & \cos(13\theta) & \cos(15\theta) \\ \cos(2\theta) & \cos(6\theta) & \cos(10\theta) & \cos(14\theta) & \cos(18\theta) & \cos(22\theta) & \cos(26\theta) & \cos(30\theta) \\ \cos(3\theta) & \cos(9\theta) & \cos(15\theta) & \cos(21\theta) & \cos(27\theta) & \cos(33\theta) & \cos(39\theta) & \cos(45\theta) \\ \cos(4\theta) & \cos(12\theta) & \cos(20\theta) & \cos(28\theta) & \cos(36\theta) & \cos(44\theta) & \cos(52\theta) & \cos(60\theta) \\ \cos(5\theta) & \cos(15\theta) & \cos(25\theta) & \cos(35\theta) & \cos(45\theta) & \cos(55\theta) & \cos(65\theta) & \cos(75\theta) \\ \cos(6\theta) & \cos(18\theta) & \cos(30\theta) & \cos(42\theta) & \cos(54\theta) & \cos(66\theta) & \cos(78\theta) & \cos(90\theta) \\ \cos(7\theta) & \cos(21\theta) & \cos(35\theta) & \cos(49\theta) & \cos(63\theta) & \cos(77\theta) & \cos(91\theta) & \cos(105\theta) \end{bmatrix}$$

and finally

$$T = \begin{bmatrix} 0.6376 & 0.2986 & -0.0585 & 0.0241 & -0.0125 & 0.0071 & -0.0039 & 0.0018 \\ 0.4223 & 0.8433 & 0.3227 & -0.0710 & 0.0311 & -0.0164 & 0.0088 & -0.0039 \\ -0.0827 & 0.3227 & 0.8893 & 0.3057 & -0.0624 & 0.0259 & -0.0125 & 0.0053 \\ 0.0341 & -0.0710 & 0.3057 & 0.8978 & 0.3004 & -0.0585 & 0.0223 & -0.0086 \\ -0.0177 & 0.0311 & -0.0624 & 0.3004 & 0.9018 & 0.2969 & -0.0546 & 0.0170 \\ 0.0100 & -0.0164 & 0.0259 & -0.0585 & 0.2969 & 0.9057 & 0.2916 & -0.0460 \\ -0.0056 & 0.0088 & -0.0125 & 0.0223 & -0.0546 & 0.2916 & 0.9143 & 0.2745 \\ 0.0025 & -0.0039 & 0.0053 & -0.0086 & 0.0170 & -0.0460 & 0.2745 & 0.9603 \end{bmatrix}$$

Notice that further improvements can be done, as for example
use approximated values for the T matrix or the T matrix can
be computed without the $\sqrt{1/2}$ terms of the P matrix. Those
terms can be included after the T matrix is computed.

The computational complexity for computing of N/2 out of N
points, i.e. downscaling by a factor of 2, is $O_M=N(N+2)/8$ and
$O_A=(N(N+6)-1)/8$. For the computation of 8 out of 16
coefficients (i.e. N=16) 36 multiplications and 43 additions
are required. More specifically the computation of the even
indexed coefficients requires 4 multiplications by $\sqrt{1/2}$ and 4
additions. The computation of $G=Y_1-Z_1'$ requires 8
subtractions and the computation of R requires 32
multiplications and 28 additions (only the upper 4x8 elements
of the T matrix are used, since only coefficients X_i,
i=1,3,5,7 have to be calculated). 3 post additions are needed
for calculating the required odd-indexed coefficients from R.

Special cases

a. When only the first 4 out of the 8 coefficients Y_k, Z_k'
are non-zero (i.e. $Y_k = Z_k'=0$ for k=4,5,6,7), then the above
given complexity becomes 20 multiplications and 23 additions.
Specifically the computation of the even indexed coefficients
requires 4 multiplications by $\sqrt{1/2}$ and 4 additions, the
computation of $G=Y_1-Z_1'$ requires 4 subtractions and the
computation of R requires 16 multiplications and 12 additions
(since only the upper 4x4 elements of the T matrix are used).
3 post additions are needed for calculating the required odd-
indexed coefficients from R.

b. In all cases the 4 multiplications by $\sqrt{1/2}$ for the
computation of the even indexed coefficients could be saved
by absorbing them into the quantisation stage that follows
the TDM stage.

c. A number of operations could also be saved if the values
of the T matrix were rounded to the closest power of 2. In
such a case shifts could be used instead of multiplications.
The exploitation of the shift and add operation existing in
all modern DSPs and general purpose CPUs would also increase
performance considerably.

In the case of down-scaling 4 adjacent 8x8 DCT blocks down to one 8x8 block, i.e. down-sizing by a factor of 2 in each dimension, by means of the row-column method, the proposed algorithm has to be applied 24 times. I.e. 16 times across the rows and 8 times across the columns as shown in Fig. 5a. This gives a computational complexity of 864 multiplications and 1032 additions or a total of 1896 operations (additions plus multiplications).

In the special case that only the upper left 4x4 DCT coefficients of each 8x8 block are non-zero, the algorithm has to be applied 16 times only, i.e. 8 times across each dimension, as shown in Fig. 5b. This results to a complexity of 320 multiplications and 368 additions or a total of 688 operations.

The above given complexity figures could be further reduced if approximate values, e.g. powers of 2, for the T matrix elements were used.

Considering that 11 multiplications and 29 additions are needed for each DCT or IDCT computation , a total of 1008 multiplications and 1752 additions or 2760 operations are required for down-scaling four adjacent 8x8 DCT blocks down to one 8x8 block according to the approach depicted in Fig. 3a. The comparison of this complexity to that needed for the case of Fig. 5a, 1896 operations are needed (or 31.3% are saved). In the special case of Fig. 5b, the computational savings are about 64%.

Down-sampling of compressed images in the transform domain is not only advantageous from the computational point of view, but from the obtained picture quality as well. This is due to the fact that a great number of arithmetic and quantisation errors are avoided. The values of the T matrix can be off-line calculated to the desired accuracy and the sum of products for the computation of TG can also be calculated to

the desired accuracy. No intermediate calculation steps of lower accuracy are needed.

The method can also be used for downscaling of video sequences in standards like H.261/263, MPEG 1/2/4. The application of the method is scalable video coding, as in frequency scalability schemes is also possible, as described in PCT/SE98/00448.

Also, in transcoder applications, a transcoder can be arranged to downscale the compressed images. For example, in video transcoding the method as described herein can be used for intra and inter macroblocks in video coding standards. In that case the motion vectors are scaled accordingly.

Thus, by using the algorithm as described herein encoding and decoding when processing digital images in the compressed domain many advantages in terms of processing speed, storage efficiency and image quality are obtained.

CLAIMS

1. An encoder having means for calculating the DCT of a
sequence of length N/2, N being a positive, even integer, and
having means for calculating a DCT of length N directly from
two sequences of length N/2 representing the first and second
half of an original sequence of length N, **characterised in**
that the means for calculating DCTs of length N/2 are
arranged to calculate the even coefficients of a DCT of
length N as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2\kappa\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]\kappa\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}[Y_k + (-1)^k Z_k] = \sqrt{\frac{1}{2}}[Y_k + Z'_k] \quad k = 0,1,\ldots,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\ldots,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n-z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} \text{ or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1},$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,\ldots,(N/2)-1$ and

$$= \left\{\sqrt{\frac{2}{N/2}}\sum_{i=0}^{\frac{N}{2}-1}\varepsilon_i(Y_i-Z'_i)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}$$

2. An encoder having means for calculating the DCT of a
sequence of length N/2xN/2, N being a positive, even integer
having means for calculating an NxN DCT directly from four
DCTs of length (N/2xN/2) representing the DCTs of four
adjacent blocks constituting the NxN block, **characterised in**
that the means for calculating DCTs of length N/2 are
arranged to calculate the even coefficients of a DCT of
length N as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2\kappa\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]\kappa\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}\left[Y_k + (-1)^k Z_k\right] = \sqrt{\frac{1}{2}}\left[Y_k + Z'_k\right] \quad k = 0,1,...,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,...,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} \text{ or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1},$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,...,(N/2)-1$ and $\left\{\sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}$

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3. An encoder according to any of claims 1 - 2, **characterised in** that N is equal to 2^m, m being a positive integer > 0.

4. A decoder having means for calculating the DCT of a sequence of length N/2, N being a positive, even integer having means for calculating a DCT of length N directly from two sequences of length N/2 representing the first and second half of an original sequence of length N, **characterised in** that the means for calculating DCTs of length N/2 are arranged to calculate the even coefficients of a DCT of length N as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2k\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]k\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}[Y_k + (-1)^k Z_k] = \sqrt{\frac{1}{2}}[Y_k + Z'_k] \quad k = 0,1,\ldots,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\ldots,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} \text{ or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1},$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,\ldots,(N/2)-1$ and $\left\{\sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}$

5. A decoder having means for calculating the DCT of a
sequence of length N/2xN/2, N being a positive, even integer
having means for calculating an NxN DCT directly from four
DCTs of length (N/2xN/2) representing the DCTs of four
adjacent blocks constituting the NxN block. **characterised in**
that the means for calculating DCTs of length N/2 are
arranged to calculate the even coefficients of a DCT of
length N as:

$$
X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2\kappa\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}
$$

$$
= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]\kappa\pi}{2(N/2)}\right]\right\}
$$

$$
= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}
$$

$$
= \sqrt{\frac{1}{2}}\left[Y_k + (-1)^k Z_k\right] = \sqrt{\frac{1}{2}}\left[Y_k + Z'_k\right] \quad k = 0,1,\ldots,(N/2)-1.
$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\ldots,(N/2)-1$.

And the odd index coefficients as

$$
X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}
$$

$$
= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}\text{or}
$$

$$
X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1},
$$

$$
r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}
$$

where $k = 0,1,\ldots,(N/2)-1$ and

$$
= \left\{\sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}
$$

6. A decoder according to any of claims 4 - 5, **characterised**
in that N is equal to 2^m, *m* being a positive integer > 0.

7. A transcoder comprising an encoder or decoder according to any of claims 1 - 6.

8. A transcoder according to claim 7, **characterised in** that the transcoder is arranged to downscale a compressed image.

9. A system for transmitting DCT transformed image or video data comprising an encoder or decoder according to any of claims 1 - 6.

10. A method of encoding an image in the compressed (DCT) domain, using DCTs of lengths N/2 and wherein the compressed frames are undersampled by a certain factor in each dimension, wherein an NxN DCT is directly calculated from 4 adjacent N/2xN/2 blocks of DCT coefficients of the incoming compressed frames, N being a positive, even integer, **characterised in** that the even coefficients of a DCT of length N are calculated as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2k\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]k\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)k\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}\left[Y_k + (-1)^k Z_k\right] = \sqrt{\frac{1}{2}}\left[Y_k + Z'_k\right] \quad k = 0,1,\ldots,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\ldots,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}} \left\{ \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k-1)\pi}{2N} \right\}$$

$$= \frac{1}{\varepsilon_k} \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} (y_n - z'_n) 2\cos\frac{(2n+1)\pi}{2N} \cos\frac{(2n+1)k\pi}{2(N/2)} \right\} \text{ or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k} \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} r_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\} - X_{2k-1} \text{ ,}$$

$$r_n = (y_n - z'_n) 2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,\ldots,(N/2)-1$ and $\left\{ \sqrt{\frac{2}{N/2}} \sum_{l=0}^{\frac{N}{2}-1} \varepsilon_l (Y_l - Z'_l) \cos\frac{(2n+1)l\pi}{2(N/2)} \right\} 2\cos\frac{(2n+1)\pi}{2N}$

11. A method of encoding an image represented as a DCT transformed sequence of length N, N being a positive, even integer, wherein the DCT is calculated directly from two sequences of length N/2 representing the first and second half of the original sequence of length N, **characterised in** that the even coefficients of a DCT of length N are calculated as:

$$X_{2k} = \sqrt{\frac{2}{N}} \varepsilon_{2k} \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)2k\pi}{2N} = \sqrt{\frac{2}{N}} \varepsilon_k \left\{ \sum_{n=0}^{\frac{N}{2}-1} x_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=N/2}^{N-1} x_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\}$$

$$= \sqrt{\frac{2}{N}} \varepsilon_k \left\{ \sum_{n=0}^{\frac{N}{2}-1} y_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1} x_{N-1-n} \cos\left[\frac{[2(N-1-n)+1]k\pi}{2(N/2)} \right] \right\}$$

$$= \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} y_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} z_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\}$$

$$= \sqrt{\frac{1}{2}} \left[Y_k + (-1)^k Z_k \right] = \sqrt{\frac{1}{2}} \left[Y_k + Z'_k \right] \quad k = 0,1,\ldots,(N/2)-1.$$

where Z'_l is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,\ldots,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}} \left\{ \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k-1)\pi}{2N} \right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}}\varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)} \right\} \text{ or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}}\varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} r_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\} - X_{2k-1} \text{ ,}$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,...,(N/2)-1$ and

$$= \left\{ \sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)} \right\}2\cos\frac{(2n+1)\pi}{2N}$$

12. A method according to any of claims 10 - 11,
characterised in that N is equal to 2^m, m being a positive integer > 0.

13. A method of decoding an image represented as a DCT transformed sequence of length N, N being a positive, even integer, wherein the DCT is calculated directly from two sequences of length N/2 representing the first and second half of the original sequence of length N, , **characterised in** that the even coefficients of a DCT of length N are calculated as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)2k\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k \left\{ \sum_{n=0}^{\frac{N}{2}-1} x_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=N/2}^{N-1} x_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k \left\{ \sum_{n=0}^{\frac{N}{2}-1} y_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1} x_{N-1-n} \cos\left[\frac{[2(N-1-n)+1]k\pi}{2(N/2)}\right] \right\}$$

$$= \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}}\varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} y_n \cos\frac{(2n+1)k\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} z_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\}$$

$$= \sqrt{\frac{1}{2}}[Y_k + (-1)^k Z_k] = \sqrt{\frac{1}{2}}[Y_k + Z'_k] \quad k = 0,1,...,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,...,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = \sqrt{\frac{2}{N}}\left\{\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)(2k-1)\pi}{2N}\right\}$$

$$= \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}(y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} \text{ or }$$

$$X_{2k+1} = \frac{1}{\varepsilon_k}\sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}r_n\cos\frac{(2n+1)k\pi}{2(N/2)}\right\} - X_{2k-1} \text{ ,}$$

$$r_n = (y_n - z'_n)2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,...,(N/2)-1$ and

$$= \left\{\sqrt{\frac{2}{N/2}}\sum_{l=0}^{\frac{N}{2}-1}\varepsilon_l(Y_l - Z'_l)\cos\frac{(2n+1)l\pi}{2(N/2)}\right\}2\cos\frac{(2n+1)\pi}{2N}$$

14. A method of decoding an image in the compressed (DCT) domain, using DCTs of lengths N/2 and wherein the compressed frames are undersampled by a certain factor in each dimension, wherein an NxN DCT is directly calculated from 4 adjacent N/2xN/2 blocks of DCT coefficients of the incoming compressed frames, N being a positive, even integer, , **characterised in** that the even coefficients of a DCT of length N are calculated as:

$$X_{2k} = \sqrt{\frac{2}{N}}\varepsilon_{2k}\sum_{n=0}^{N-1}x_n\cos\frac{(2n+1)2\kappa\pi}{2N} = \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=N/2}^{N-1}x_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{2}{N}}\varepsilon_k\left\{\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sum_{n=0}^{\frac{N}{2}-1}x_{N-1-n}\cos\left[\frac{[2(N-1-n)+1]\kappa\pi}{2(N/2)}\right]\right\}$$

$$= \sqrt{\frac{1}{2}}\left\{\sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}y_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)} + \sqrt{\frac{2}{N/2}}\varepsilon_k\sum_{n=0}^{\frac{N}{2}-1}z_n\cos\frac{(2n+1)\kappa\pi}{2(N/2)}\right\}$$

$$= \sqrt{\frac{1}{2}}[Y_k + (-1)^k Z_k] = \sqrt{\frac{1}{2}}[Y_k + Z'_k] \quad k = 0,1,...,(N/2)-1.$$

where Z'_k is the DCT of $z'_n = x_{N-1-n}$, $n = 0,1,...,(N/2)-1$.

And the odd index coefficients as

$$X_{2k+1} + X_{2k-1} = = \sqrt{\frac{2}{N}} \left\{ \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k+1)\pi}{2N} + \sum_{n=0}^{N-1} x_n \cos\frac{(2n+1)(2k-1)\pi}{2N} \right\}$$

$$= \frac{1}{\varepsilon_k} \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} (y_n - z'_n) 2\cos\frac{(2n+1)\pi}{2N} \cos\frac{(2n+1)k\pi}{2(N/2)} \right\} \text{or}$$

$$X_{2k+1} = \frac{1}{\varepsilon_k} \sqrt{\frac{1}{2}} \left\{ \sqrt{\frac{2}{N/2}} \varepsilon_k \sum_{n=0}^{\frac{N}{2}-1} r_n \cos\frac{(2n+1)k\pi}{2(N/2)} \right\} - X_{2k-1} ,$$

$$r_n = (y_n - z'_n) 2\cos\frac{(2n+1)\pi}{2N}$$

where $k = 0,1,...,(N/2)-1$ and $\left\{ \sqrt{\frac{2}{N/2}} \sum_{l=0}^{\frac{N}{2}-1} \varepsilon_l (Y_l - Z'_l) \cos\frac{(2n+1)l\pi}{2(N/2)} \right\} 2\cos\frac{(2n+1)\pi}{2N}$

15. A method according to any of claims 13 - 14,
characterised in that N is equal to 2^m, m being a positive
integer > 0.

Transcoding Stage | Decoding Stage

Quantised Transform Coefficients → Q^{-1} → DCT^{-1} → LPF → | → DCT → Q | Q^{-1} → DCT^{-1} → Reconstructed Downscaled image (a)

Quantised Transform Coefficients → Q^{-1} → 4x4 out of 8x8 → Q | Q^{-1}_{4x4} → DCT^{-1}_{4x4} → Reconstructed Downscaled image (b)

Quantised Transform Coefficients → Q^{-1} → TDM → Q | Q^{-1} → DCT^{-1} → Reconstructed Downscaled image (c)
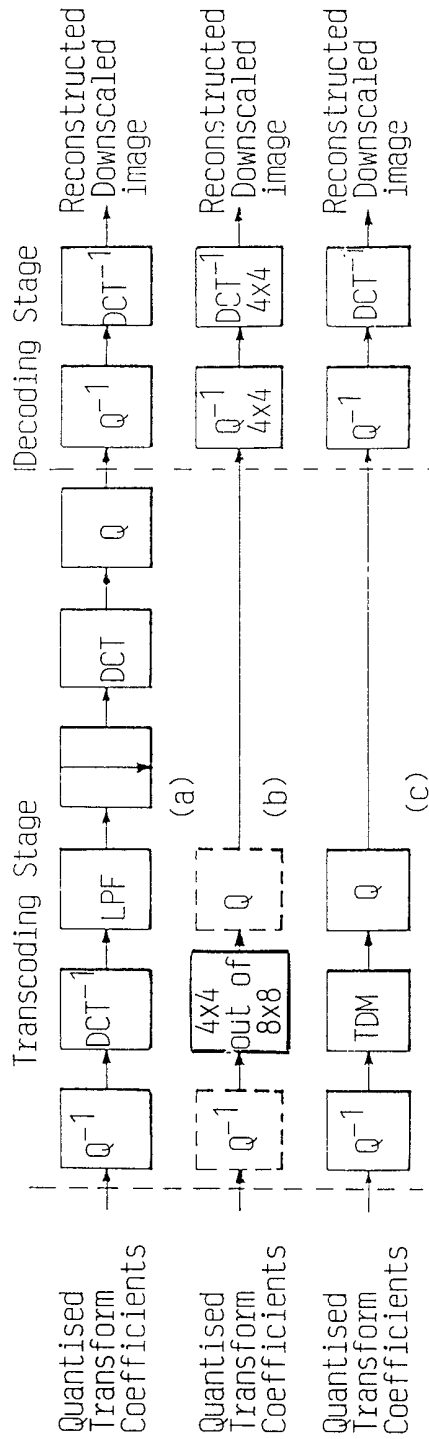
FIG. 1

Notes: i. DCT/DCT denote the forward and the inverse Discrete Cosine Transform on 8x8 data, unless otherwise stated
ii. The steps of lossless coding and decoding of the quantised data are not depicted in the above diagrams
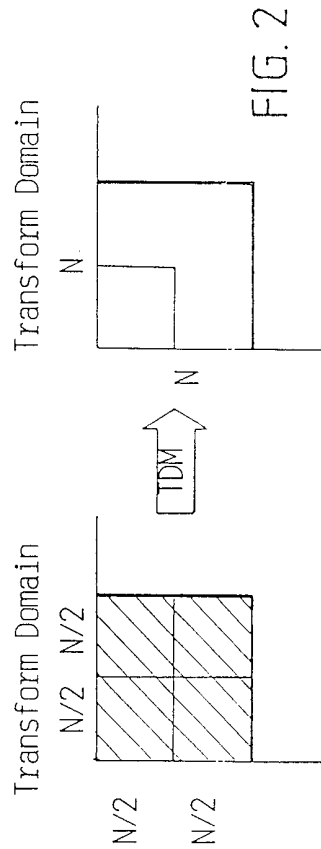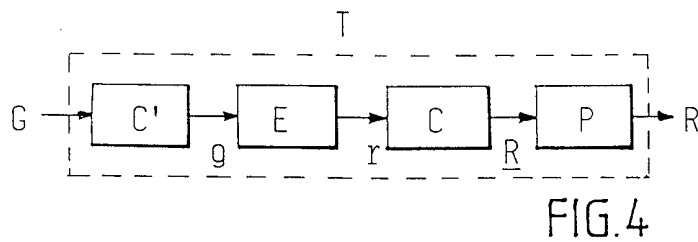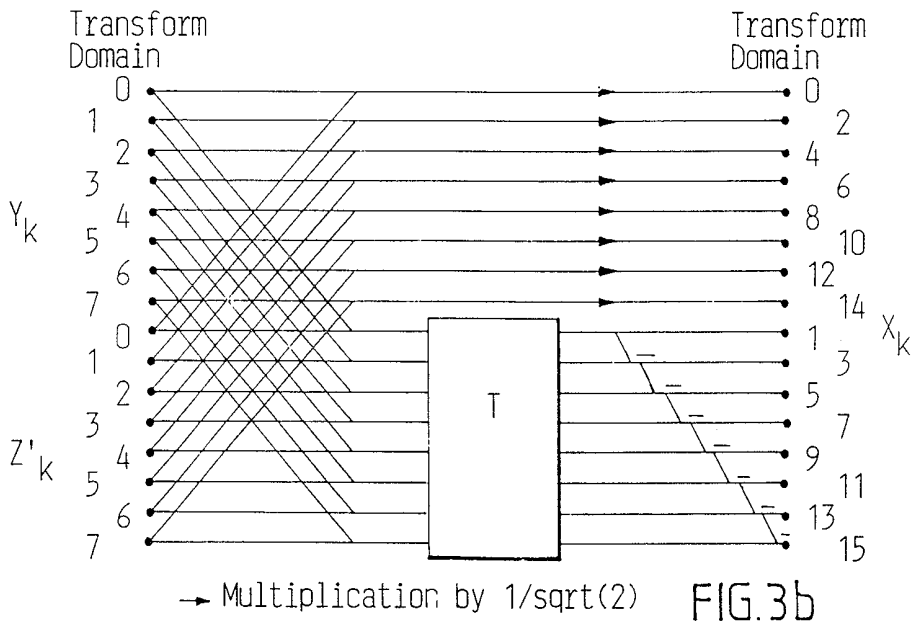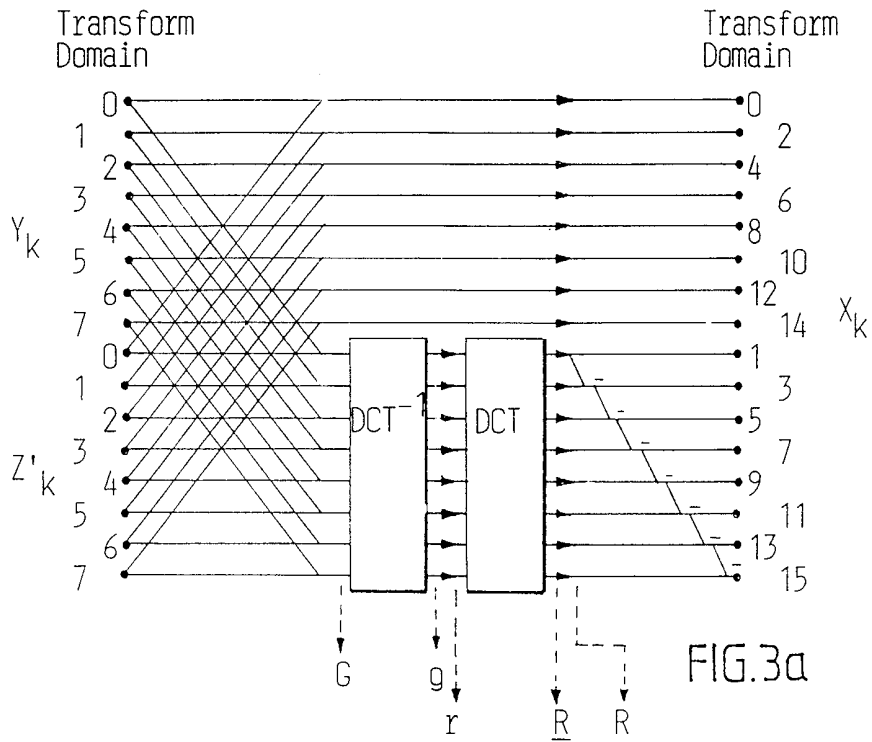iii. TDM stands for Transform Domain Manipulation

Transform Domain

N/2 N/2

N/2 / N/2 (hatched)

→ TDM →

Transform Domain

N × N

FIG. 2

2 / 3

FIG.3a

→ Multiplication by 1/sqrt(2)   FIG.3b

FIG.4
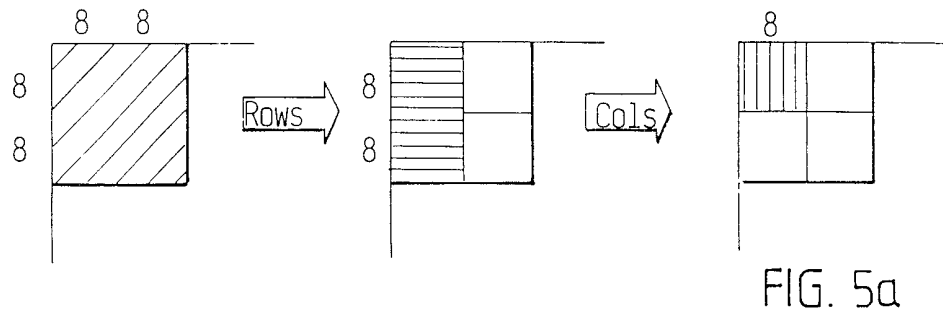
FIG. 5a

FIG. 5b

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G06F 17/14, G06T 9/00, H04N 7/30
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G06F, G06T, H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5528533 A (AOI KITAURA ET AL), 18 June 1996 (18.06.96)	1-15
A	US 5452104 A (CHONG U. LEE), 19 Sept 1995 (19.09.95)	1-15
A	US 5107345 A (CHONG U. LEE), 21 April 1992 (21.04.92)	1-15
A	US 5363096 A (PIERRE DUHAMEL ET AL), 8 November 1994 (08.11.94)	1-15

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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*    Special categories of cited documents:
"A"  document defining the general state of the art which is not considered
     to be of particular relevance
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     cited to establish the publication date of another citation or other
     special reason (as specified)
"O"  document referring to an oral disclosure, use, exhibition or other
     means
"P"  document published prior to the international filing date but later than
     the priority date claimed
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     date and not in conflict with the application but cited to understand
     the principle or theory underlying the invention
"X"  document of particular relevance: the claimed invention cannot be
     considered novel or cannot be considered to involve an inventive
     step when the document is taken alone
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     considered to involve an inventive step when the document is
     combined with one or more other such documents, such combination
     being obvious to a person skilled in the art
"&"  document member of the same patent family
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Date of the actual completion of the international search	Date of mailing of the international search report
4 November 1999	30 -11- 1999

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Jan Silfverling/cs Telephone No. + 46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report			Publication date	Patent family member(s)			Publication date
US	5528533	A	18/06/96	JP	6266747	A	22/09/94
US	5452104	A	19/09/95	AT	159396	T	15/11/97
				AU	658432	B	13/04/95
				AU	2186692	A	08/01/93
				CA	2110264	A	10/12/92
				DE	69222766	D,T	07/05/98
				DK	587783	T	04/05/98
				EP	0587783	A,B	23/03/94
				SE	0587783	T3	
				ES	2110504	T	16/02/98
				FI	935477	A	07/12/93
				GR	3025624	T	31/03/98
				JP	6511361	T	15/12/94
				NO	305299	B	03/05/99
				NO	934396	A	07/01/94
				WO	9222166	A	10/12/92
				AT	171332	T	15/10/98
				AU	653715	B	13/10/94
				AU	7476391	A	18/09/91
				CA	2076865	A,C	28/08/91
				DE	69130214	D,T	20/05/99
				EP	0517834	A,B	16/12/92
				SE	0517834	T3	
				ES	2126569	T	01/04/99
				FI	923811	A	25/08/92
				NO	303260	B	15/06/98
				US	5021891	A	04/06/91
				US	5107345	A	21/04/92
				WO	9113514	A	05/09/91
US	5107345	A	21/04/92	AT	171332	T	15/10/98
				AU	653715	B	13/10/94
				AU	7476391	A	18/09/91
				CA	2076865	A,C	28/08/91
				DE	69130214	D,T	20/05/99
				EP	0517834	A,B	16/12/92
				SE	0517834	T3	
				ES	2126569	T	01/04/99
				FI	923811	A	25/08/92
				NO	303260	B	15/06/98
				US	5021891	A	04/06/91
				US	5452104	A	19/09/95
				WO	9113514	A	05/09/91
US	5363096	A	08/11/94	CA	2066471	A	25/10/92
				DE	69209129	D,T	07/11/96
				EP	0511095	A,B	28/10/92
				FR	2675969	A,B	30/10/92
				JP	5145428	A	11/06/93