A multiresolution transform and reversible YIQ color transform for video compression

ABSTRACT

[0001] A transform is multi-resolution and has low complexity. The transform consists of the S+P transform cascaded with a Haar transform of the high-pass signal cascaded with a reordering of the coefficients cascaded with an additional prediction. A reversible YIQ color transform is also described.

REFERENCES CITED

U.S. Patent Documents

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Other References

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"Reversible Image compression via multiresolution representation and predictive coding," by Amir Said and William A. Pearlman, presented at the SPIE VCIP Symposium, Cambridge, MA, Nov. 1993.

A. Said and W.A. Pearlman, "A New Fast and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees", IEEE Trans. on Circuits and Systems for Video Technology, vol. 6., pp. 243--250, June 1996.

Geoff Davis and Aria Nosratinia, "Wavelet-Based Image Coding: An Overview", Applied and Computational Control, Signals, and Circuits, Vol. 1, No. 1, Spring 1998.

S. Fukuma, et al., "Lossless 8-Point Fast Discrete Cosine Transform Using Lossless Hadamard Transform", Shingaku Giho IEICE, DSP99-103, ICD99-190, IE99-65, pp. 37-44 (Oct. 1999).

Shinji FUKUMA, Masahiro IWAHASHI and Noriyoshi KAMBAYASHI. "Lossless Color Coordinate Transform for Lossless Color Image Coding". IEEE Asia-Pacific Conference on Circuits and Systems **(APCCAS),** FT23 (1.1) [595-598], (1998.11)

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable.

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING COMPACT DISC APPENDIX

Not Applicable.

CLAIMS

I claim,

1. A machine transforms light signals into electric or magnetic signals and includes, as one step of the transformation, a packet transform consisting of the S+P transform cascaded with one level of the Haar transform.

2. A machine as in claim 1 in which the coefficients resulting from the Haar transform step of the packet transform are reordered as explained in the DETAILED DESCRIPTION section.

3. A machine transforms the electric or magnetic signals into light signals and includes, as one step of the transformation, a step which reverses the transforms in claim 1 or claims 1 and 2.

4. Image or video compression or decompression using the reversible YIQ color transform described in the DETAILED DESCRIPTION section.

BACKGROUND

Transform-Based Coding

[0002] Transform coding is a compression technique used in many audio, image and video compression systems. Uncompressed digital image and video is typically represented or captured as samples of picture elements or colors at locations in an image or video frame arranged in a two-dimensional (2D) grid. This is referred to as a spatial-domain representation of the image or video. For example, a typical format for images consists of a stream of 24-bit color picture element samples arranged as a grid. Each sample is a number representing color components at a pixel location in the grid within a color space, such as RGB, or YIQ, among others. Various image and video systems may use various different color, spatial and time resolutions of sampling. Similarly, digital audio is typically represented as time-sampled audio signal stream. For example, a typical audio format consists of a stream of 16-bit amplitude samples of an audio signal taken at regular time intervals.

[0003] Uncompressed digital audio, image and video signals can consume considerable storage and transmission capacity. Transform coding reduces the size of digital audio, images and video by transforming the spatial-domain representation of the signal into a frequency-domain (or other like transform domain) representation, and then reducing resolution of certain generally less perceptible frequency components of the transform-domain representation. This generally produces much less perceptible degradation of the digital signal compared to reducing color or spatial resolution of images or video in the spatial domain, or of audio in the time domain.

S + P

[0004] The S transform is defined as,

$$l[n] = \text{floor}((c[2n] + c[2n + 1]) / 2)$$
$$h[n] = c[2n] - c[2n + 1]$$

[0005] In normalized representation, this becomes,

$$l[n] = (c[2n] + c[2n + 1]) / \text{sqrt}(2)$$
$$h[n] = (c[2n] - c[2n + 1]) / \text{sqrt}(2)$$

[0006] In the S+P transform (see A. Said and W.A. Pearlman, "An Image Multiresolution Representaion for Lossless and Lossy Compression, "IEEE Trans. on Image Processing, vol. 5, pp. 1303--1310, Sept. 1996.), the P step with predictor A is, in normalized representation,

$$h[n] = h[n] - (l[n - 1] - l[n + 1]) / 8$$

Prior art

[0007] Wavelet packet transforms have previously been studied (see Geoff Davis and Aria Nosratinia, "Wavelet-Based Image Coding: An Overview", Applied and Computational Control, Signals, and Circuits, Vol. 1, No. 1, Spring 1998). However, S+P is not always a wavelet transform. And reordering of coefficients has not been previously used with wavelet packets. In one embodiment, one level of the S+P transform in 2 dimensions is done as one level of the 2 dimensional Haar transform cascaded with a prediction step. In a preferred embodiment, this prediction step is different from what it would be if it was a wavelet transform.

Lossless YIQ

[0008] A lossless YIQ color transform had previously been designed which requires 7 multiplications per pixel (see Shinji FUKUMA, Masahiro IWAHASHI and Noriyoshi KAMBAYASHI. "Lossless Color Coordinate Transform for Lossless Color Image Coding". IEEE Asia-Pacific Conference on Circuits and Systems **(APCCAS),** FT23 (1.1) [595-598], (1998.11)).

SUMMARY

[0009] The domain of the present invention is transform coding of images or video. One such transform is the S+P transform. The S+P transform is improved by cascading a Haar transform as the second step of a packet transform cascaded with a reordering of the coefficients resulting from the second-step Haar transform so that in each pair the coefficient which resembles a difference is on the left of or above the coefficient which resembles an average. This is cascaded with an additional prediction on the AC coefficients which are linear along one axis and quadratic along the other axis

[0010] The improved transform is low complexity and usually has energy compaction properties better than the Daubechies 6 wavelet. It usually has fewer high-frequency artifacts near image boundaries than the Daubechies 6 wavelet.

[0011] The reversible YIQ color transform in the present invention requires 2 or 5 multiplications per pixel, which is less complex than the prior art which requires 7 multiplications per pixel.

DESCRIPTION OF THE DRAWINGS

Not Applicable.

DETAILED DESCRIPTION

[0012] This invention describes a machine consisting of a digital camera connected to a computer which includes a storage device. The storage device may be fixed or removable. Examples of a removable storage device is a floppy disk or a magnetic tape. The camera may capture still images or motion sequences. The machine captures light signals and stores them as electric or magnetic signals on the storage device. At one step of the transformation, the improved transform is performed.

[0013] The present invention transform is:

- Perform one level of S+P on all columns and all rows. Set the level of the new tranform to zero.

- Do one stage of the new transform on all columns and rows as follows:
- * Perform a S+P transform on coefficients at even locations.
- * Perform a Haar transform on coefficients at odd locations.
- * Reorder the results of the Haar transform of coefficients at odd locations so that the coefficient resembling a difference is on the left of the coefficient resembling a sum.

- Increment the level of the new transform by 1 and repeat the previous step by performing one stage of the new transform on coefficients at locations that are multiples of 2^n both horizontally and vertically with n being the level of the new transform.

[0014] This description assumes the lifting representation in which the high-pass signal is interspersed with the low pass signal. The S transform may be normalized or not normalized. The description provided in the claims and the one in this section are equivalent. The coefficient reordering is done so that the entropy coder can expect lower frequencies on the left. Any of the predictors of the S+P transform may be used. The S and Haar transforms may

be done in 2D or in 1D on the rows and columns. The S and Haar transforms may be done in integer or floating point.

[0015] Following is sample C code that implements the present invention transform:

```
------------------------------------------------------------
static void haar(int n, float c[])
{
    int i;
    float t1, t2;

    if(!(i = n >> 1)) return;
    for(;;){
        t1 = *c;
        t2 = *(c + 1);
        *c = (t1 + t2) * M_SQRT1_2;
        *(c + 1) = (t1 - t2) * M_SQRT1_2;
        if(!(--i)) return;
        c += 2;
    }
}

static void haar_reorder(int n, float c[], int inc)
{
    int i;
    float t1, t2;

    if(!(i = n >> 1)) return;
```

```
    for(;;){
        t1 = *c;
        t2 = *(c + inc);
        *c = (t1 - t2) * M_SQRT1_2;
        *(c + inc) = (t1 + t2) * M_SQRT1_2;
        if(!--i) return;
        c += 2 * inc;
    }
}

static void s_plus_p_a(int n, float c[], int inc)
{
    int i;
    float pred, buffer[n];

    for(i = 0; i < n; i ++){
        buffer[i] = c[i * inc];
    }
    haar(n, buffer);
    for(i = 0; i < n; i += 2){
        if(i) pred = buffer[i - 2] - buffer[i];
        else pred = 0;
        if(i + 4 <= n) pred += buffer[i] - buffer[i + 2];
        buffer[i + 1] -= pred * 0.125;
    }
    for(i = 0; i < n; i ++){
        c[i * inc] = buffer[i];
    }
```

```
}

static void new_transform_vector(int n, float c[], int inc)
{
    haar_reorder(n >> 1, c + inc, 2 * inc);
    s_plus_p_a((n + 1) >> 1, c, 2 * inc);
}

void new_transform(int width, int height, float **lines)
{
    int h, v, x, y, level;

    for(x = 0; x < width; x ++){
        s_plus_p_a(height, lines[0] + x, width);
    }
    for(y = 0; y < height; y ++){
        s_plus_p_a(width, lines[y], 1);
    }
    v = height;
    h = width;
    for(level = 0; ; level ++){
        for(x = 0; x < width; x += 1 << level)
            new_transform_vector(v, lines[0] + x, width <<
level);
        for(y = 0; y < height; y += 1 << level)
            new_transform_vector(h, lines[y], 1 << level);
        h = (h + 1) >> 1;
        v = (v + 1) >> 1;
```

```
        if((h < 2) && (v < 2)) return;
    }
}
```

[0016] The present invention can be described in two ways. One way is as a combination of 1D transforms on rows and columns as above. The other way is as a packet transform of S+P and one level of the Haar transform cascaded with a reordering of coefficients cascaded with an additional prediction of the AC coefficients which are linear along one axis and quadratic along the other axis. This explains the formulation of the claims.

[0017] After the improved transform step, the signal may be entropy-coded using the SPIHT algorithm (see A. Said and W.A. Pearlman, "A New Fast and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees, "IEEE Trans. on Circuits and Systems for Video Technology, vol. 6., pp. 243--250, June 1996.).

[0018] In another embodiment of the invention, a machine consists of a display or light projector connected to a computer containing a storage device. The machine transforms the electric or magnetic signals from the storage device into light signals. At one step of the transformation, the invention improved transform is reversed.

[0019] The present invention also includes a reversible YIQ color transform. Reversible means that the color transform maps integers to integers in such a way that after a cycle of transforming RGB coordinates into YIQ then back to RGB again, the output is exactly the same as the input. The reversible YIQ color transform with a rotation of theta degrees is,

```
R -= B
B += R >> 1
```

```
B -= G
G += B >> 1
G += round(- (0.5 - Kb - Kr) * B + (Kr - Kb) * R / 2.0)
B -= round(((1 - cos(45 - theta)) / sin(45 - theta)) * R)
R += round(sin(45 - theta) * B)
B -= round((((1 - cos(45 - theta)) / sin(45 - theta)) - sin(45
- theta) * cos(45 - theta) / (4 - sin(45 - theta) * sin(45 -
theta))) * R)
Y = G
I = R
Q = B
```

[0020] The reverse involves inverting all the steps in reverse order:

```
G = Y
R = I
B = Q
B += round((((1 - cos(45 - theta)) / sin(45 - theta)) - sin(45
- theta) * cos(45 - theta) / (4 - sin(45 - theta) * sin(45 -
theta))) * R)
R -= round(sin(45 - theta) * B)
B += round(((1 - cos(45 - theta)) / sin(45 - theta)) * R)
G -= round(- (0.5 - Kb - Kr) * B + (Kr - Kb) * R / 2.0)
G -= B >> 1
B += G
B -= R >> 1
R += B
```

[0021] The reversible YIQ color transform in the present invention has the property that the I and Q components are orthogonal.