CONSTRANDED ONE-BIT TRANSFORM FOR RETINEX BASED MOTION ESTIMATION FOR SEQUENCES WITH BRIGHTNESS VARIATIONS

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ABSTRACT
In this paper, we propose a DCT based binary matching approach for fast motion estimation. The proposed approach is suitable to be applied to our previously proposed retinex based coding system which is characterized with fast motion estimation and the capability of accurately estimating motions for sequences having inter-frame brightness variations. We propose to apply the DCT techniques to the transformation of images to the binary bit plane and to the scaled retinex domain, which is more computationally efficient compared to the conventional convolution based bit transformation approach. Experimental results show that our proposed DCT based bit transform has a very close prediction quality performance (less than 0.1dB drop) to that of the convolution based approach while our system can avoid the extra convolution procedure.

Index Terms – Motion estimation, video coding, two-bit transform (2BT), discrete cosine transform, H.264

1. INTRODUCTION
Conventional motion estimation (ME) methods[1] make use of the brightness constancy assumption, which assumes that object brightness remains constant between frames. However, for sequences with inter-frame brightness variations, the assumption is no longer valid and compression efficiency decreases. To handle brightness variations, the H.264 adopts the weighted prediction[2] approach. However, this feature is only effective for varying brightness of spatially uniform light source. The primary target application is the fade in/out and gradual scene change effects. To cope with spatially non-uniform brightness variations, we proposed previously a DCT based retinex system[3] for accurate motion estimation, which effectively removes the inter-frame de-correlation factor resulting from brightness variations. In this paper, we propose a fast motion estimation approach based on our previous work using an approach similar to the constrained one-bit transform[4] to facilitate Boolean Exclusive-OR (EX-OR) matching. Our proposed system is characterized with fast computation and the capability of accurately estimating motions under brightness variation environment. In[5], a multiplication free one-bit transform (1BT) based motion estimation approaches was proposed using the convolution techniques. Recently, two-bit transform (2BT)[4, 6] based approaches were introduced to enhance the accuracy in the motion estimation stage.

2. REVIEW OF PREVIOUS WORK
In this section, we briefly describe our previous work[3]. To model the influence of light source on image, Barrow and Tenenbaum[7] assumed the observed image \( I(x,t) \) being a product of two components: a reflectance image \( R(x,t) \) and an illumination image \( L(x,t) \).

\[
I(x,t) = R(x,t)L(x,t)
\]

To decompose an image, an assumption has to be imposed. Land et al.[8] proposed the Retinex Theory which imposes the spatial smoothness assumption on the illumination image \( L(x,t) \). Instead of using the Gaussian filtering operations, we proposed to use the DCT techniques to estimate the illumination image \( L(x,t) \) to facilitate video coding.

\[
L_d(x,t) = \text{IDCT}(\text{Clip}(\text{DCT}(I(x,t))))
\]

where \( \text{Clip}() \) is a function to preserve the first \((N/4+1)N/2\) low frequency coefficients in the zigzag scan order with \( N \) standing for the number of levels. The DCT coefficients are quantized and de-quantized with a quantization factor \( \text{DCTQ} \) before inverse DCT and the quantized coefficients are coded and sent to the decoder as the overhead bits for coding \( L_d(x,t) \). The corresponding retinex output is

\[
R_d(x,t) = \log I(x,t) - \log L_d(x,t)
\]

Subsequently, the floating point values of \( R_d(x,t) \) from \(-K\) to \( K \) are then mapped (with upper and lower clipping) and quantized to integers ranging from 0 to 255. We refer the mapped image to the scaled retinex image (SRI). Fig. 1(a) and (c) show the block diagrams for transforming an image to and from the scaled retinex image respectively. We implemented the scheme and applied it to the multiple reference frame motion compensation environment of H.264. Figs. 1(b) and (d) show the encoding and decoding system diagrams for P slices respectively. Each macroblock can be coded either in the conventional pixel domain or the scaled retinex domain with independent motion estimation. Mode
decision is made based on the mode giving the lowest rate-distortion cost. In summary, in addition to the conventional data, we need to transmit the bits for coding \( L_d(x,t) \) for each image, and one pixel/retinex mode selection bit for each macroblock. The retinex based system is characterized with its high accuracy in estimated motion for sequences with brightness variations to improve coding efficiency.

\[
\text{CNNMP}(\text{mv}_i) = \Sigma \{ |\text{CM}(x, t) \cdot \text{CM}(x+\text{mv}_i, t-1)| \} \\
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\text{CNNMP}(\text{mv}_i) = \Sigma \{ |\text{CM}(x, t) \cdot \text{CM}(x+\text{mv}_i, t-1)| \}
\]

where \( \text{mv}_i \) is a candidate motion vector and \( \text{SRi}(x,t) \) is the image \( I(x,t) \) in the scaled retinex domain. To increase the computational efficiency, we propose to perform the binary block matching using a two-bit transform. The advantage of bit transform is that it allows an 8-bit pixel being represented by 2 bits such that only 2 bytes are required to store 8 pixels(points). Thus, matching operations for the 8 pixels can be done concurrently by simple binary operations, instead of 8 subtraction operations in the conventional matching process. The applied 2BT is a modification of the constrained 1BT proposed in [4]. Instead of using a multi-

band-pass filtered image of \( I(x,t) \), we make use of the computed illumination image \( L_d(x,t) \) in (2) which is essentially a low pass image. The image \( L_d(x,t) \) is compared against the original image \( I(x,t) \) to construct the binary bit plane \( B(x,t) \) and it is mainly used as a sort of pixel-wise threshold.

\[
B(x,t) = 1 , \text{if } I(x,t) \geq L_d(x,t) \\
= 0, \text{otherwise}
\]

Generally, \( B(x,t) \) represents the high frequency components of the image which is suitable for ME. In order to increase the accuracy in 1BT matching process, a constrain mask \( \text{CM}(x,t) \) is computed so as to avoid including pixels that have values close to the transform threshold.

\[
\text{CM}(x,t) = 1 , \text{if } |I(x,t) - L_d(x,t)| \geq D \\
= 0, \text{otherwise}
\]

where \( D \) is a user defined value. \( \text{CM}(x,t) \) value of 1 indicates that this pixel is reliable for the 1BT matching process. This mask can effectively increase the accuracy of motion estimation by excluding pixels from homogeneous area.

In the search process of the motion estimation, instead of using (4), the constrained number of non-matching points (CNNMP) measure is used.

\[
\text{CNNMP}(\text{mv}_i) = \Sigma \{ |\text{CM}(x, t) \cdot \text{CM}(x+\text{mv}_i, t-1)| \} \\
\text{CNNMP}(\text{mv}_i) = \Sigma \{ |\text{CM}(x, t) \cdot \text{CM}(x+\text{mv}_i, t-1)| \}
\]

where \( l \) and \( \& \) denote Boolean OR, AND and Exclusive-OR operations respectively. Pixels that have values close to the transform threshold will be counted as a match regardless of their 1BT value. The candidate motion vector \( \text{mv}_i \) scoring the lowest CNNMP value is designated to be the block motion vector. If two candidate motion vectors result the same CNNMP, the one having the smaller motion vector magnitude is chosen. With the selected motion vector, motion compensation is done in the scaled retinex domain followed by the prediction error coding as shown in Fig. 1. In summary, the binary bit plane \( B(x,t) \) and the constrain mask \( \text{CM}(x,t) \) are generated and stored only in the encoder for fast motion estimation purpose. No extra bit is sent to the decoder and the decoder is identical to the one shown in Fig. 1(d). The computational saving should be similar to the constrained 1BT proposed in [4].

Fig. 2 shows the first image of sequence Stefan, the generated mask image \( \text{CM}(x,t) \) with \( D=18 \) and the corresponding 1BT generated using our proposed DCT based 1BT and the multiplication free 1BT proposed in [5]. It is seen from the mask image \( \text{CM}(x,t) \) that the pixels in the homogeneous area are classified as unreliable and are excluded from 1BT matching process.

3. PROPOSED DCT BASED CONSTRAINED 1-BIT TRANSFORM

In this paper, we propose a fast approach for the ME using binary matching algorithm suitable for the DCT based retinex system. Originally, the motion vectors are estimated using the conventional sum-of-absolut-difference(SAD) approach in the scaled retinex domain.

\[
\text{SAD}(\text{mv}_i) = \Sigma \text{SRI}(x,t) - \text{SRI}(x+\text{mv}_i, t-1)|
\]

where \( \text{mv}_i \) is a candidate motion vector and \( \text{SRI}(x,t) \) is the image \( I(x,t) \) in the scaled retinex domain. To increase the computational efficiency, we propose to perform the binary block matching using a two-bit transform. The advantage of bit transform is that it allows an 8-bit pixel being represented by 2 bits such that only 2 bytes are required to store 8 pixels(points). Thus, matching operations for the 8 pixels can be done concurrently by simple binary operations, instead of 8 subtraction operations in the conventional matching process. The applied 2BT is a modification of the constrained 1BT proposed in [4]. Instead of using a multi-
and “Foreman”) and 3 sequences with brightness variations.

“StefanFading” (originally sequence “Stefan”) involves using two sequences without brightness variation (“Stefan” and “Foreman”) and its variant 1BT (without CM(x,t)) using DCT based approach(DCT-2BT-SR and DCT-1BT-SR respectively).

Note, the abbreviation name with “SR” indicates the retinex approach(DCT-2BT-SR and DCT-1BT-SR respectively) and our proposed binary matching with constrained 1BT(Conv-1BT-SR and Conv-2BT-SR respectively) using convolution based approach(Conv-1BT-SR and Conv-2BT-SR respectively) and previous proposed retinex based video coding system with our proposed DCT based constrained 1BT method is very efficient in terms of the high computational efficiency and the capability of accurately estimating the motions under brightness variation environment.

5. CONCLUSION

In this paper, we propose a DCT based binary matching approach for fast motion estimation to be applied in our previously proposed retina-based video coding system which is characterized with the capability of accurately estimating motions under brightness variations environment. Instead of using the convolution based bit transformation techniques, we propose to use the DCT based bit transform which facilitates both the transformation of image into the binary bit plane and the scaled retinex image domain. Experimental results show that our proposed DCT based bit transform has a very close prediction quality performance to that of the convolution based approach while our system can avoid the extra convolution procedure.

6. ACKNOWLEDGEMENT

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7. REFERENCES


Table 1
Average PSNR(dB) of sequences reconstructed by various ME techniques (full search, block size = 16x16, search range = 16 pixels)

<table>
<thead>
<tr>
<th>Video sequences (frame size, sequence length)</th>
<th>Stefan (352x240, 100)</th>
<th>Foreman (352x288, 100)</th>
<th>Stefan-Fading (352x240, 100)</th>
<th>Camera-Flash (320x240, 24)</th>
<th>SpotLight-Panning (320x240, 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stefan (352x240, 100)</td>
<td>25.09</td>
<td>32.92</td>
<td>29.1</td>
<td>16.19</td>
<td>26.76</td>
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<tr>
<td>Foreman (352x288, 100)</td>
<td>25.07</td>
<td>32.83</td>
<td>29.32</td>
<td>26.81</td>
<td>28.63</td>
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<tr>
<td>Stefan-Fading (352x240, 100)</td>
<td>24.23</td>
<td>30.08</td>
<td>28.42</td>
<td>25.32</td>
<td>27.7</td>
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<td>Camera-Flash (320x240, 24)</td>
<td>23.92</td>
<td>31.39</td>
<td>28.72</td>
<td>26.17</td>
<td>26.9</td>
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<td>SpotLight-Panning (320x240, 40)</td>
<td>23.71</td>
<td>30.37</td>
<td>28.48</td>
<td>26.36</td>
<td>28.35</td>
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</table>

*Proposed algorithm

Table 2
Average PSNR(dB) of sequences reconstructed by various ME techniques (full search, block size = 8x8, search range = 16 pixels)

<table>
<thead>
<tr>
<th>Video sequences (frame size, sequence length)</th>
<th>Stefan (352x240, 100)</th>
<th>Foreman (352x288, 100)</th>
<th>Stefan-Fading (352x240, 100)</th>
<th>Camera-Flash (320x240, 24)</th>
<th>SpotLight-Panning (320x240, 40)</th>
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<tbody>
<tr>
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<td>26.27</td>
<td>34.35</td>
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<td>30.46</td>
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<td>25.59</td>
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<td>28.15</td>
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</tbody>
</table>

*Proposed algorithm

Table 3
Average PSNR(dB) of sequences reconstructed by various ME techniques (full search, block size = 4x4, search range = 16 pixels)

<table>
<thead>
<tr>
<th>Video sequences (frame size, sequence length)</th>
<th>Stefan (352x240, 100)</th>
<th>Foreman (352x288, 100)</th>
<th>Stefan-Fading (352x240, 100)</th>
<th>Camera-Flash (320x240, 24)</th>
<th>SpotLight-Panning (320x240, 40)</th>
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<td>Stefan (352x240, 100)</td>
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<td>27.87</td>
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<td>30.20</td>
<td>26.82</td>
<td>25.95</td>
<td>28.20</td>
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</table>

*Proposed algorithm