# Fast Motion Estimation Algorithm Using Dual Bit-plane Matching Criteria 

Changryoul Choi and Jechang Jeong
Dept. of Electronics and Computer Engineering,
Hanyang University, Seoul, Korea

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## Introduction (1)

## - Motion Estimation

- Motion Estimation (ME)

Process to get the best matched motion block in the reference frame within the search range according to some matching criterion compared with motion block in the current frame


## Introduction (2)

## - Motion Estimation

- Motion estimation
- Key role to reduce the temporal redundancy
- Most computationally demanding, consuming up to $90 \%$ of the total encoder power


## Introduction (3)

## - Matching Criterion

: some sort of a metric for measuring the similarity between the reference motion block and the current motion block.
-SSD (Sum of Squared Differences)

$$
\operatorname{SSD}(u, v)=\sum_{i=0}^{N-1} \sum_{j=0}^{N-1}(C B(i, j)-R B(i+u, j+v))^{2}
$$

-SAD (Sum of Absolute Differences)

$$
S A D(u, v)=\sum_{i=0}^{N-1} \sum_{j=0}^{N-1}|C B(i, j)-R B(i+u, j+v)|
$$

where CB and RB represent the current motion block and reference motion block, respectively, $-s \leq u, v \leq s$ ( $s$ is the search range), and $N \times N$ is the motion block size.

## Bit-wise Matching Criterion (1)

## - Bit-wise Matching Criterion

: Since the computation of the matching criterion of SAD is very high, the bit-wise matching criteria instead of typical SAD were introduced as a matching criterion. The benefit of using the bit-wise matching criterion is two-fold
-Fast calculation of matching criterion

- Reduced bandwidth during the calculation of the matching criterion and the related stuff


## Bit-wise Matching Criterion (2)

## - One-bit Transform (1BT)

: 1BT-based ME where the reference frames and the current frames are transformed into one-bit representations by comparing the original image frame against a bandpass filtered output was proposed. Each frame $I$ is filtered with a $17 \times 17$ kernel K which is given as :

$$
K(i, j)=\left\{\begin{array}{l}
1 / 25, \text { if } i, j \in[0,4,8,12,16] \\
0, \text { otherwise }
\end{array}\right.
$$

## Bit-wise Matching Criterion (3)

## - One-bit Transform (1BT)

: the following is the 1BT :

$$
B(i, j)= \begin{cases}1, & I(i, j) \geq I_{F}(i, j) \\ 0, & \text { otherwise }\end{cases}
$$

where $I_{F}$ is the filtered frame. The corresponding matching criterion, the Number of Non-Matching Points, is given as :

$$
N N M P_{1 B T}(m, n)=\sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left\{B^{t}(i, j) \oplus B^{t-1}(i+m, j+n)\right\}
$$

where $B^{t}(i, j)$ and $B^{t-1}(i, j)$ are the 1 BT representations of the current and the previous image frames, respectively, $\oplus$ denotes the Boolean XOR operation, the motion block size is $N \times N$, and $-s \leq m, n \leq s$ is the search range.

## Bit-wise Matching Criterion (4)

- Other Matching Criterion
- Multiplication-free 1BT(MF1BT)
- Two-bit Transform (2BT)
- Constrained 1BT (C1BT)
- Truncated Gray-coded Bit-plane Matching (TGCBPM)
- Weightless TGCBPM (WTGCBPM)
- Constrained 2BT (C2BT)
- Bit-inverted Gray-coded Bit-plane Matching (BGCBPM)
- Etc.


## Bit-wise Matching Criterion (5)

## - Constrained Two-bit Transform (C2BT)

-The C2BT was recently proposed exploiting the pros of the C 1 BT and 2BT.

- The computational complexity of the C2BT is less than $50 \%$ of that of C 1 BT and multiplication-free.
- The PSNR performance of the C2BT is better than that of the C 1 BT and that of the 2 BT .

|  | add. | mul. | Shift | sub. | comp. | Total <br> Operation |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1BT | 25 | 1 | - | - | 1 | 27 |
| 2BT | 2.8125 | 1.0625 | - | 0.03125 | 3 | 6.90625 |
| C1BT | 16 | - | 1 | 1 | 2 | 20 |
| C2BT | 1.1133 | - | 0.015625 | 1.0642 | 3 | 5.193125 |

## Bit-wise Matching Criterion (6)

- Matching Criterion of C2BT

$$
\begin{aligned}
& N N M P_{C 2 B T, 1}(m, n)=\sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left\{C_{1}^{t}(i, j) \oplus C_{1}^{t-1}(i+m, j+n)\right\} \\
& N N M P_{C 2 B T, 2}(m, n)=\sum_{i=0}^{N-N} \sum_{j=0}^{N-1}\left\{C_{2}^{t}(i, j) \oplus C_{2}^{t-1}(i+m, j+n)\right\} \\
& N N M P_{C 2 B T, 3}(m, n)=2 \times \sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left[C_{2}^{t}(i, j) \bullet\left\{C_{1}^{t}(i, j) \oplus C_{1}^{t-1}(i+m, j+n)\right\}\right] \\
& N N M P_{C 2 B T, 4}(m, n)=2 \times \sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left[C_{2}^{t-1}(i+m, j+n) \bullet\left\{C_{1}^{t}(i, j) \oplus C_{1}^{t-1}(i+m, j+n)\right\}\right] \\
& N N M P_{C 2 B T}(m, n)=\sum_{i=1}^{4} N N M P_{C 2 B T, i}(m, n)
\end{aligned}
$$

## Bit-wise Matching Criterion (7)

## - Bit-inverted Gray-coded BPM (BGCBPM)

-The BGCBPM was recently proposed using the bit-inverted Gray-codes.

$$
h_{k}=\sim g_{k}, \quad N T B \leq k \leq K-1
$$

- Its matching criterion output is designed to be similar to the typical SAD and shows the superior performance compared to the typical TGCBPM and the WTGCBPM.


## Bit-wise Matching Criterion (8)

- Matching Criterion of BGCBPM

$$
\begin{aligned}
& N N M P_{\text {gram, }}(m, n)=\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \sum_{k=N T B}^{K-1} h_{k}^{t}(i, j) \oplus h_{k}^{t-1}(i+m, j+n) \\
& N N M P_{\text {gram,2 }}(m, n) \\
& =2^{K-N T B} \times \sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left[h_{K-2}^{t}(i, j) \bullet\left\{h_{K-1}^{t}(i, j) \oplus h_{K-1}^{t-1}(i+m, j+n)\right\}\right] \\
& N N M P_{\text {gram, }}(m, n) \\
& =2^{K-N T B} \times \sum_{i=0}^{N-1} \sum_{j=0}^{N-1}\left[h_{K-2}^{t-1}(i, j) \bullet\left\{h_{K-1}^{t}(i, j) \oplus h_{K-1}^{t-1}(i+m, j+n)\right\}\right] \\
& N N M P_{\text {BGCBPM }}(m, n)=\sum_{i=1}^{3} N N M P_{\text {gram, }, i}(m, n)
\end{aligned}
$$

## Proposed Algorithm(1)

## - Motivations

-The computational complexity of transformations for attaining the bit-planes using C2BT and BGCBPM are very low.
-The average ME accuracy of the C2BT is better than that of BGCBPM using 2 bit-planes but worse than that of BGCBPM using 3 bit-planes.
-Their ME accuracy heavily dependent upon the sequences. -Therefore, using the multiple candidate searches into these two matching criterion can enhance the overall ME accuracy substantially.

- And their matching criteria are very similar.


## Proposed Algorithm(2)

## - Proposed Algorithm

-The proposed algorithm can be summarized as follows:

1. Find three candidate motion vectors using three different matching criteria. (C2BT, BGCBPM, and Hybrid which is given as

$$
N N M P_{\text {HYBRID }}(m, n)=N N M P_{C 2 B T}(m, n)+N N M P_{\text {BCCBPM }}(m, n)
$$

2. If three candidate motion vectors are the same, declare it as the best motion vector and go to 4 .
3. Calculate SADs of the three candidate motion vectors and declare the motion vector with the least SAD as the best motion vector.
4. Go to the next current block.

## Experimental Results (1)

## - Experimental Setup

- Test Sequences : 17 CIF size ( $352 \times 288$ ) sequences using only the first 100 -frame
- Test Algorithms : 1BT, C2BT, BGCBPM, AM2BT, FSBMA, and the proposed algorithm
- Motion Block Size : $16 \times 16$
- Search Range : $\pm 16$
- Searching Order: Spiral order
- Measure : PSNR (dB), \# of SAD calculations (in "()")


## Experimental Results (2)

| sequences | 1BT | C2BT | $\begin{aligned} & \text { BGCBPM } \\ & \text { (NTB = 6) } \end{aligned}$ | $\begin{aligned} & \text { BGCBPM } \\ & (\text { NTB }=5) \end{aligned}$ | AM2BT | Proposed (NTB = 6) | Proposed (NTB = 5) | FSBMA |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| stefan | 25.12 | 25.56 | 25.63 | 25.71 | $\begin{gathered} 25.68 \\ (23.95) \end{gathered}$ | $\begin{aligned} & 25.73 \\ & (0.62) \end{aligned}$ | $\begin{aligned} & 25.74 \\ & (0.62) \end{aligned}$ | 25.75 |
| football | 22.64 | 23.75 | 23.64 | 23.95 | $\begin{gathered} 23.96 \\ (56.76) \end{gathered}$ | $\begin{aligned} & 24.01 \\ & (0.84) \end{aligned}$ | $\begin{aligned} & 24.03 \\ & (0.68) \end{aligned}$ | 24.00 |
| akiyo | 41.66 | 42.58 | 42.08 | 42.61 | $\begin{aligned} & 42.57 \\ & (0.57) \end{aligned}$ | $\begin{aligned} & 42.79 \\ & (0.08) \end{aligned}$ | $\begin{aligned} & 42.81 \\ & (0.08) \end{aligned}$ | 42.84 |
| foreman | 31.69 | 32.32 | 32.00 | 32.83 | $\begin{aligned} & 32.60 \\ & (3.26) \end{aligned}$ | $\begin{aligned} & 33.15 \\ & (1.05) \end{aligned}$ | $\begin{aligned} & 33.31 \\ & (1.03) \end{aligned}$ | 33.43 |
| mobile | 23.50 | 23.79 | 23.82 | 23.87 | $\begin{gathered} 23.84 \\ (37.24) \end{gathered}$ | $\begin{aligned} & 23.91 \\ & (0.36) \end{aligned}$ | $\begin{aligned} & 23.92 \\ & (0.33) \end{aligned}$ | 23.92 |
| hall | 32.13 | 33.68 | 33.22 | 34.03 | $\begin{aligned} & 33.81 \\ & (2.82) \end{aligned}$ | $\begin{aligned} & 34.27 \\ & (0.85) \end{aligned}$ | $\begin{aligned} & 34.28 \\ & (0.86) \end{aligned}$ | 34.34 |
| coastguard | 29.09 | 29.49 | 28.09 | 29.49 | $\begin{aligned} & 29.55 \\ & (7.85) \end{aligned}$ | $\begin{aligned} & 29.59 \\ & (0.68) \end{aligned}$ | $\begin{aligned} & 29.61 \\ & (0.41) \end{aligned}$ | 29.62 |
| container | 37.57 | 38.20 | 37.67 | 37.70 | $\begin{aligned} & 38.16 \\ & (0.59) \end{aligned}$ | $\begin{aligned} & 38.32 \\ & (0.15) \end{aligned}$ | $\begin{aligned} & 38.30 \\ & (0.26) \end{aligned}$ | 38.33 |
| bus | 23.86 | 24.59 | 24.66 | 24.84 | $\begin{gathered} 24.79 \\ (35.79) \end{gathered}$ | $\begin{aligned} & 24.88 \\ & (0.72) \end{aligned}$ | $\begin{aligned} & 24.91 \\ & (0.62) \end{aligned}$ | 24.90 |

## Experimental Results (3)

| sequences | 1BT | C2BT | $\begin{aligned} & \text { BGCBPM } \\ & \text { (NTB = 6) } \end{aligned}$ | $\begin{aligned} & \text { BGCBPM } \\ & \text { (NTB = 5) } \end{aligned}$ | AM2BT | Proposed $(\mathrm{NTB}=6)$ | Proposed $(\mathrm{NTB}=5)$ | FSBMA |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| dancer | 29.67 | 30.99 | 30.48 | 31.16 | $\begin{gathered} 31.45 \\ (11.37) \end{gathered}$ | $\begin{aligned} & 31.78 \\ & (1.54) \end{aligned}$ | $\begin{aligned} & 31.87 \\ & (1.57) \end{aligned}$ | 32.14 |
| mother and daughter | 37.58 | 39.27 | 37.48 | 39.49 | $\begin{aligned} & 39.58 \\ & (1.18) \end{aligned}$ | $\begin{aligned} & 39.93 \\ & (0.78) \end{aligned}$ | $\begin{aligned} & 39.99 \\ & (0.75) \end{aligned}$ | 40.12 |
| tempete | 27.01 | 27.53 | 27.46 | 27.61 | $\begin{gathered} 27.63 \\ (19.10) \end{gathered}$ | $\begin{aligned} & 27.68 \\ & (0.46) \end{aligned}$ | $\begin{aligned} & 27.69 \\ & (0.41) \end{aligned}$ | 27.70 |
| table tennis | 27.44 | 28.54 | 28.31 | 28.62 | $\begin{gathered} 28.65 \\ (10.61) \end{gathered}$ | $\begin{aligned} & 28.79 \\ & (0.84) \end{aligned}$ | $\begin{aligned} & 28.83 \\ & (0.81) \end{aligned}$ | 28.87 |
| flower | 25.73 | 25.95 | 25.86 | 25.98 | $\begin{gathered} 25.97 \\ (22.36) \end{gathered}$ | $\begin{aligned} & 26.02 \\ & (0.62) \end{aligned}$ | $\begin{aligned} & 26.02 \\ & (0.55) \end{aligned}$ | 26.03 |
| children | 28.05 | 29.01 | 29.11 | 29.17 | $\begin{gathered} 29.16 \\ (17.64) \end{gathered}$ | $\begin{aligned} & 29.27 \\ & (0.25) \end{aligned}$ | $\begin{aligned} & 29.27 \\ & (0.23) \end{aligned}$ | 29.24 |
| paris | 30.16 | 30.57 | 30.53 | 30.67 | $\begin{aligned} & 30.58 \\ & (7.33) \end{aligned}$ | $\begin{aligned} & 30.72 \\ & (0.29) \end{aligned}$ | $\begin{aligned} & 30.73 \\ & (0.26) \end{aligned}$ | 30.71 |
| news | 35.58 | 36.89 | 36.81 | 37.04 | $\begin{aligned} & 37.05 \\ & (3.05) \end{aligned}$ | $\begin{aligned} & 37.30 \\ & (0.23) \end{aligned}$ | $\begin{aligned} & 37.32 \\ & (0.26) \end{aligned}$ | 37.33 |
| Average | 29.91 | 30.75 | 30.40 | 30.87 | $\begin{gathered} 30.88 \\ (15.38) \end{gathered}$ | $\begin{aligned} & 31.07 \\ & (0.61) \end{aligned}$ | $\begin{aligned} & 31.10 \\ & (0.57) \end{aligned}$ | 31.13 |

## Conclusions \& Discussions (1)

- A multiple search fast motion estimation algorithm using dual bitplane matching criteria ( C 2 BT and BGCBPM ) are proposed.
- Exploiting the low computational complexity of transformations in attaining bit-planes and almost the identical operations in two different matching error criteria (C2BT and BGCBPM), we can efficiently determine three candidate motion vectors according to the respective matching criteria and another hybrid matching criterion.
- And using the multiple candidate search strategy, we can enhance the overall motion estimation accuracy substantially.


## Conclusions \& Discussions (2)

- Experimental results show that the proposed algorithm achieves peak signal-to-noise ratio (PSNR) gains about 1.19 dB and 0.35 dB on average compared with the 1BT-based motion estimation and that of the C2BT.
-Compared with AM2BT, the proposed algorithm achieves PSNR gains about 0.22 dB and the relative computational complexity is about $1 / 27$.
- Surprisingly, the PSNR performance between the proposed algorithm and the FSBMA is only 0.03 dB and for some sequences its ME performance shows better results than the FSBMA.


## Thank you

## for your attention! Q \& A

