Fast Sub-pixel Motion Estimation Using FFT-based Full Search Block Matching

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Abstract—We propose a fast sub-pixel motion estimation algorithm with the sum of squared differences (SSD) criterion.

I. INTRODUCTION

BM is widely used in many fields, including image inpainting and video sequence coding. Since sub-pixel BM is of great help in improving accuracy of motion estimation, BM must be executed with sub-pixel accuracy. However, BM with sub-pixel accuracy comes with a heavy computational load.

II. PREPARATION

(A) Block matching with pixel accuracy

Let \( b(x,y) (x = 0,1,\ldots,A-1, y = 0,1,\ldots,B-1) \) be a macroblock and \( f(x,y) (x = 0,1,\ldots,M-1, y = 0,1,\ldots,N-1) \) be a search window. The purpose of BM is to find the particular that yields the minimum matching criterion (e.g. SSD).

\[
\text{SSD}_b(f(u,v)) = \sum_{y=0}^{B-1} \sum_{x=0}^{A-1} (b(x,y) - f(u+x,v+y))^2,
\]

where \((u,v) \in \mathbb{R}_{IN}\) is assumed to have the period \((M,N)\). The shift amount \((u,v)\) that yields the minimum \(\text{SSD}_b(f(u,v))\) is equal to that of the SSD of \(f(u,v)\). \(P_f(u,v)\) can be calculated recursively and \(\text{cor}_{gs,f}(u,v)\) can be calculated by using the FFT.

(B) FFT-based full-search BM [1]

Another matching criterion \(E_b,f(u,v)\) is defined as

\[
E_b(f(u,v)) = P_{f2}(u,v) - 2\text{cor}_{gs,f}(u,v),
\]

where

\[
P_{f2}(u,v) = \sum_{y=0}^{B-1} \sum_{x=0}^{A-1} (f(u+x,v+y))^2,
\]

\[
\text{cor}_{gs,f}(u,v) = \sum_{y=0}^{N-1} \sum_{x=0}^{M-1} b(x,y)f(u+x,v+y),
\]

and \((u,v) \in \mathbb{R}_{IN}\). \(f(x,y)\) is assumed to have the period \((M,N)\). The shift amount \((u,v)\) that yields the minimum \(E_b,f(u,v)\) is equal to that of the SSD of \(f(u,v)\). \(P_f(u,v)\) can be calculated recursively and \(\text{cor}_{gs,f}(u,v)\) can be calculated by using the FFT.

(C) BM with sub-pixel accuracy

Sub-pixel BM is generally achieved using pixels generated by interpolation in the spatial region. If the linear interpolation is used, the interpolated values \(\hat{f}(u,v,\alpha,\beta)(x,y)\) is written as

\[
\hat{f}(u,v,\alpha,\beta)(x,y) = (1-\alpha)(1-\beta)f(u+x,v+y) + \alpha(1-\beta)f(u+x+1,v+y) + (1-\alpha)\beta f(u+x,v,y+1) + \alpha\beta f(u+x+1,v,y+1),
\]

where \(0 \leq \alpha < 1,0 \leq \beta < 1,0 \leq u + \alpha < M - A\) and \(0 \leq v + \beta < N - B\).

III. PROPOSED METHOD

The criterion \(E_{b,f(u,v)}(u,v)\) between the macroblock and the interpolated value \(\hat{f}(u,v,\alpha,\beta)(x,y)\) is given by

\[
E_{b,f(u,v)}(u,v) = (1-\alpha)^2[1-\beta]^2P_{f2}(u,v)+\beta^2P_{f2}(u,v+1)+2\beta[1-\beta]P_{fH}(u,v)+
\]

\[
+2\alpha[1-\beta]P_{fV}(u,v)+\beta^2P_{fV}(u,v+1)+2\beta[1-\beta]P_{fD}(u,v)+
\]

\[
+2\alpha[1-\beta]P_{fH}(u,v+1)+\beta^2P_{fH}(u,v+1)+2\beta[1-\beta]P_{fD}(u,v+1)+2\alpha[1-\beta]P_{fV}(u,v+1)+\beta^2P_{fV}(u,v+1)+
\]

\[
+2\beta[1-\beta]P_{fD}(u,v)+\beta^2P_{fD}(u,v+1),
\]

and \((u,v) \in \mathbb{R}_{IN}\). \(P_{f2}(u,v)\) can be calculated recursively.

IV. SIMULATIONS

We simulated the motion compensation by using the 0-1 frames of the “caltrain” (512 x 400, 8-bit grayscale) video sequences. The macroblock and search window sizes were fixed at 16 x 16 and 64 x 64, respectively. We executed sub-pixel BM per 1/2, 1/4, and 1/8 pixels within ±0.5 pixels from the resultant shift amount with pixel accuracy. Table I shows processing speed.

V. CONCLUSIONS

We proposed a new fast sub-pixel motion estimation algorithm with the SSD criterion. The higher the matching accuracy is, the faster the proposed method is.

REFERENCES


TABLE I

<table>
<thead>
<tr>
<th>Method</th>
<th>Conventional</th>
<th>Proposed</th>
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<tbody>
<tr>
<td>Accuracy</td>
<td>1/2</td>
<td>1/4</td>
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<tr>
<td>Time (ms)</td>
<td>19</td>
<td>48</td>
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</table>

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