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).

$$\mathrm{SSD}_{b,f}(u,v)=\sum_{y=0}^{B-1}\sum_{x=0}^{A-1}\left(b(x,y)-f(u+x,v+y)\right)^2, \quad (1)$$

$(u,v)\in\mathbf{R}_{\mathrm{IN}}=\{(u,v)|u=0,1,\ldots,M-A \text{ and } v=0,1,\ldots,N-B\}$.

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

Another matching criterion $E_{b,f}(u,v)$ is defined as

$$E_{b,f}(u,v)=P_{f^2}(u,v)-2\mathrm{cor}_{g_b,f}(u,v), \quad (2)$$

where

$$P_{f^2}(u,v)=\sum_{y=0}^{B-1}\sum_{x=0}^{A-1}\{f(u+x,v+y)\}^2, \quad (3)$$

$$\mathrm{cor}_{g_b,f}(u,v)=\sum_{y=0}^{N-1}\sum_{x=0}^{M-1}b(x,y)f(u+x,v+y), \quad (4)$$

and $(u,v)\in\mathbf{R}_{\mathrm{IN}}$. $f(x,y)$ 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 $\mathrm{SSD}_{b,f}(u,v)$. $P_{f^2}(u,v)$ can be calculated recursively and $\mathrm{cor}_{g_b,f}(u,v)$ 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 $f_{(u,v,\alpha,\beta)}(x,y)$ is written as

$$\begin{aligned}&f_{(u,v,\alpha,\beta)}(x,y)\\&=(1-\alpha)(1-\beta)f(u+x,v+y)+\alpha(1-\beta)f(u+x+1,v+y)\\&+(1-\alpha)\beta f(u+x,v+y+1)+\alpha\beta f(u+x+1,v+y+1), \quad (5)\end{aligned}$$

$0\le\alpha<1, 0\le\beta<1, 0\le u+\alpha\le M-A$ and $0\le v+\beta\le N-B$.

TABLE I
Processing speed (milli-seconds)

Method	Conventional			Proposed		
Accuracy	1/2	1/4	1/8	1/2	1/4	1/8
Time(ms)	19	48	169	16	18	29

III. Proposed Method

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

$$\begin{aligned}&E_{b,f_{(\alpha,\beta)}}(u,v)\\&=(1-\alpha)^2\big[(1-\beta)^2P_{f^2}(u,v)+\beta^2P_{f^2}(u,v+1)+2\beta(1-\beta)P_{fH}(u,v)\big]\\&+\alpha^2\big[(1-\beta)^2P_{f^2}(u+1,v)+\beta^2P_{f^2}(u+1,v+1)+2\beta(1-\beta)P_{fH}(u+1,v)\big]\\&+2\alpha(1-\alpha)\big[(1-\beta)^2P_{fV}(u,v)+\beta^2P_{fV}(u,v+1)+\beta(1-\beta)P_{fD}(u,v)\big]\\&-2\big[(1-\alpha)(1-\beta)\mathrm{cor}_{g_b,f}(u,v)+\alpha(1-\beta)\mathrm{cor}_{g_b,f}(u+1,v)\\&+(1-\alpha)\beta\mathrm{cor}_{g_b,f}(u,v+1)+\alpha\beta\mathrm{cor}_{g_b,f}(u+1,v+1)\big], \quad (6)\end{aligned}$$

$$P_{fV}(u,v)=\sum_{y=0}^{B-1}\sum_{x=0}^{A-1}f(u+x,v+y)f(u+x+1,v+y), \quad (7)$$

$$P_{fH}(u,v)=\sum_{y=0}^{B-1}\sum_{x=0}^{A-1}f(u+x,v+y)f(u+x,v+y+1), \quad (8)$$

$$\begin{aligned}P_{fD}(u,v)=\sum_{y=0}^{B-1}\sum_{x=0}^{A-1}\big[&f(u+x,v+y)f(u+x+1,v+y+1)\\&+f(u+x+1,v+y)f(u+x,v+y+1)\big]. \quad (9)\end{aligned}$$

$P_{fV}(u,v)\sim P_{fD}(u,v)$ can be calculated recursively.

IV. Simulations

We simulated the motion compensation by using the 0-1 frames of the "caltrain" (512 × 400, 8-bit grayscale) video sequences. The macroblock and search window sizes were fixed at 16×16 and 64×64, 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

[1] Z. Li, A. Uemura, and H. Kiya, "An FFT-based full-search block-matching algorithm with SSD criterion, " in Proc. APSIPA ASC2009, pp. 457-460, Oct. 2009.

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