

Cross correlation function computation algorithm for video surveillance system.

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Abstract: *This paper describes a new algorithm to calculate cross-correlation function. We combined box filtering technique for calculation of cross correlation coefficients with parallel processing using MMX/SSE technology of modern general purpose processors. We have used this algorithm for real time optical flow estimation between frames of video sequence. Our algorithm was tested on real world video sequences obtained from the cameras of video surveillance system.*

Keywords: cross-correlation, fast algorithm, MMX/SSE extensions, optical flow, video surveillance system.

1. INTRODUCTION

Feature matching is important task in the area of computer vision. There are several different approaches for image correspondence estimation [1]. There is a group of so called area based methods [2] among them, and intensity values only are used to determine correspondence of the areas in this case. Three classes of metrics are commonly applied for area matching: cross correlation (CC), intensity differences (sum of absolute differences (SAD), sum of squared differences (SSD)), and rank [3] metrics. Cross correlation metrics is the standard statistical method for determining similarity. This metrics is more robust than the others but computationally expensive.

Feature matching is used in many problems of computer vision. One of them is optical flow estimation. Optical flow is two-dimensional vector field that represent velocities and its directions in each point of the image. It is used in many applications such as robot navigation, object tracking, video coding, and scene reconstruction. There are several different approaches to determine optical flow [4, 5]. Correlation based methods take more accurate results in the case of noise images with non rigid objects. The real world scenes to be obtained from the cameras of video surveillance system correspond to these conditions.

The main problem of most correlation based techniques is that they are computationally expensive. This fact doesn't allow use them in real time video processing. There are several ways to overcome this problem such as using optimal algorithms, application the special purposes hardware or using SIMD extension of modern general purposes processors.

Computationally optimal algorithms implement different approaches which allow the reducing computational cost for correlation. Fast Fourier transformation can be used for fast image matching algorithms [1, 5], and such technique is exploited in [6]. Approach known as box filtering technique [7] is also used for fast correlation calculation algorithm. Description of

the algorithms what compute SAD (sum of absolute differences) metrics with using box filtering technique can be found in [8, 9]. This technique in [10, 11] is used for fast NCC (normalize cross-correlation) metrics.

Using of special purposes hardware as field programmable gate array (FPGA) chips is excellent way to raise performance of data processing. Several solutions can be discovered in [12, 13] for image and video processing. Using such hardware can lead to acceptable results, but it also requires additional efforts for special computational architecture realization.

Modern general purposes processors have significant computational power, moreover they have special sets of commands for accelerating multimedia and communications applications (we mean MMX and SSE extensions).

MMX and SSE appeared accordingly in 1996 and 1999 and since then all the popular general purposes processors support these technologies. It exploits single instruction multiple data (SIMD) principle for parallel data processing. These extensions are sets new processor commands and data types. MMX allows to parallel process byte, word, double word integer values. Main disadvantage is that MMX registers in fact are FPU (floating point unit) registers with other names. It means that it isn't possible to mix MMX instructions and FPU instructions in code. SSE is elaboration of MMX and operates with packed floating-point data. Also SSE includes 12 new instructions that extend the MMX instruction set and operates MMX registers. SSE2 is elaboration of both MMX and SSE. The key benefits of SSE2 are that MMX is extended to work on 128-bit data blocks, and ability to support 64-bit floating-point values appeared.

As shown in [14] using of such extensions may be not so advantageous as special hardware, but it can assist to reduce significantly the time consumption in comparison with non MMX/SSE implementation. Examples of using MMX/SSE for digital image processing and evaluation of its productivity are presented in [15, 16, 17, 18].

In our paper we use MMX/SSE technology for developing fast box filtering technique based algorithm to perform cross correlation calculation and employ this algorithm for real time optical flow estimation.

2. FAST CROSS CORRELATION ALGORITHM

The main aim of our paper was reduction of computational costs to calculate cross correlation function. First of all we take optimal from calculating point of view method. Box filtering technique [7] is used there for fast cross correlation between frames.

2.1. Box filtering technique

Let f and g are normalized intensity's of pixels on consecutive frames. Cross correlation between regions on them can be calculated using:

$$c_{ij,d_x,d_y} = \frac{\text{cov}_{ij,d_x,d_y}(f,g)}{\sqrt{\text{var}_{ij}(f) * \text{var}_{ij,d_x,d_y}(g)}}, \quad (1)$$

where

$$\text{cov}_{ij,d_x,d_y}(f,g) = \sum_{m=j-K/2}^{j+K/2} \sum_{n=i-L/2}^{i+L/2} f_{n,m} * g_{n+d_x,m+d_y}, \quad (2)$$

$$\text{var}_{ij}(f) = \sum_{m=j-K/2}^{j+K/2} \sum_{n=i-L/2}^{i+L/2} f_{n,m}^2, \quad (3)$$

$$\text{var}_{ij,d_x,d_y}(g) = \sum_{m=j-K/2}^{j+K/2} \sum_{n=i-L/2}^{i+L/2} g_{n+d_x,m+d_y}^2, \quad (4)$$

i, j – center of matching region on f ; d_x, d_y – shift of matching region on g ; K, L – matching region size.

First and foremost we must perform the normalization. With regard to the cross-correlation it is essential for reduction of the influence of brightness and contrast changes between frames. Computing the normalization in every correlation window requires an additional processing stage. We perform it throughout the image instead of local for window. It is admissible because we process frames obtained in small time interval and when condition may be changed with low probability.

Equations (2), (3) and (4) are double sums and can be calculated using box filtering technique. They may be represented as:

$$Hsum_{ij} = \sum_{n=i-L/2}^{i+L/2} Vsum_j(n), \quad (5)$$

where

$$Vsum_j(n) = \sum_{m=j-K/2}^{j+K/2} a_{n,m} * b_{n,m}, \quad (6)$$

$Vsum_j(n)$ is the sum of products of pixel intensity values from column n of window with center in (i,j) on image a with respective values on image b .

The main idea of the technique is that for calculation $Vsum_j(n)$ it is necessary to update $Vsum_{j-1}(n)$ by subtracting from it multiplication of $a_{n,(j-K/2-1)}$ and $b_{n,(j-K/2-1)}$ which left sum because of shifting window and add multiplication of $a_{n,(j+K/2)}$ and $b_{n,(j+K/2)}$ which entered it. For calculation $Hsum_{ij}$ it is necessary to update value $Hsum_{(i-1)j}$ in the same way. Such method requires four addition-subtraction operations for new value calculation regardless of window size. Scheme of computation for reviewed technique is presented in Fig. 1.

Realization of reviewed approach requires accurate calculation strategy. First of all it is necessary to exclude

repeated calculation of the same value. For example, every value $f_{m,n}^2$ is used at the minimum two times: when it is added to the sum and then it is subtracted from it. We allocate special buffers in memory for such values.

Our algorithm works with grayscale images. It requires byte per pixel in memory for frames. Intermediate values that have to be stored require double word per pixel because they are obtained by summation of multiplications of bytes. We assign memory for pairs of buffers to store products, intermediate sums and sought sums (3) and (4). We use pairs because algorithm calculates (3) and (4) at one pass. Also we allocate memory for $L*K$ buffers to store sought sums (2). In this case algorithm does $L*K$ passes in cycle to fill each buffer and uses previously allocated for calculation (3) buffers to store products and intermediate sums. Therefore algorithm requires $N*M*(2*3+L*K)$ double words in memory for buffers.

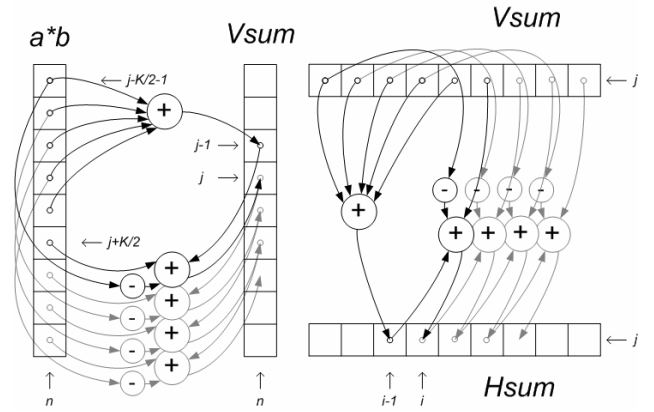


Fig. 1. Scheme of computation.

2.2. Algorithm

It is evident from Fig.1 that when $Hsum$ is calculated in each pixel of the frame it is necessary to sum up L values $Vsum$ only once for every row. Calculation of $Vsum$ requires summation of K products also only once for every column of the frame. This assertion leads to next algorithm to be presented in pseudo code.

For $x=1$ **to** number of columns **do**

 Compute $a*b$ for first K rows in column x
 (without using cycle).

 Compute $Vsum$ in row 1 and column x by
 summation K values obtained previous step
 using (6).

End

For $y=2$ **to** number of rows **do**

For $x=1$ **to** number of columns **do**

 Compute $a*b$ in row y and column x .

 Compute $Vsum$ updating previous value

$Vsum-1$

End

End

For $y=1$ to number of rows do
 Compute $Hsum$ in column 1 and row y by
 summation L values $Vsum$ using (5).
 For $x=2$ to number of columns do
 Compute $Hsum$ updating previous value
 $Hsum-1$
 End
End

2.3. Correlation coefficients calculation using SIMD extensions.

The most computational expensive stage of cross correlation function calculation is computing of equation (1). It consists of three most complex operations: multiplication, division and square root computation. Fig. 2 shows computing strategy to calculate equation (1) with using SSE commands. Organization of data storage together with SIMD parallelism allows computing four values per one pass in cycle. We achieved the largest rising in performance exactly at this stage.

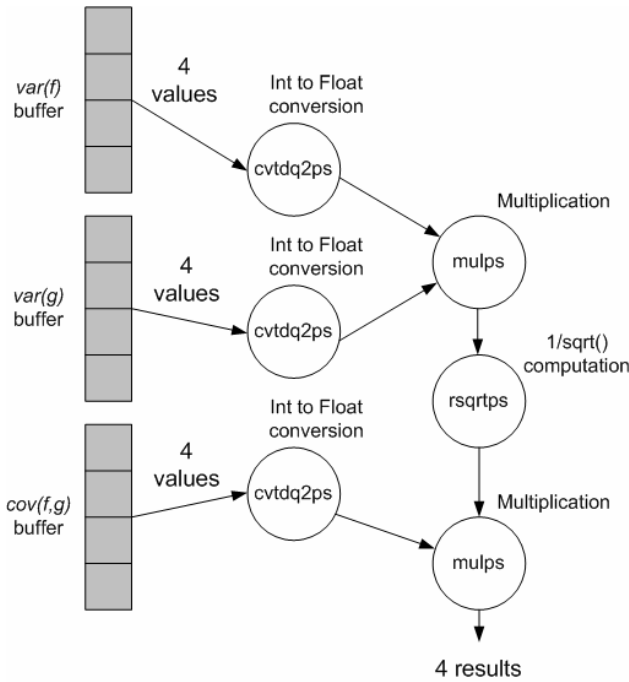


Fig. 2. Computing strategy to calculate equation (1).

2.4. Optical flow estimation.

We implemented simple correlation based method to estimate optical flow, and applied cross correlation metrics for matching regions on consecutive frames of video sequence. Our matching strategy uses correlation window to estimate correspondence of current pixel in surrounding area on previous frame. Optical flow in each point of frame is determined by maximum coefficient in sight area and size of this area depends on the size of the correlation window.

We realized the simple filter to reduce dynamic noise that appears because of discretization of analog video

image. Filtration is done by comparison difference of pixel intensity values on consecutive frames with threshold. The pixel value is changed when the mentioned difference exceeds defined value. We use this approach before correlation coefficients calculation to obtain more accurate result.

3. RESULTS

3.1. Experimental system

All calculations for this paper were performed under FreeBSD 5.0 on a processor Pentium 4 2.8 GHz with 512MB RDRAM. Performance evaluation has been done with the frames obtained from analog video camera of surveillance system. Discretization of analog video was carried out by frame grabber with BT-878 chip. It allows to obtain digital video sequences with maximum size 768x576 (PAL) or 640x480 (NTSC) and frequency 25 fps.

3.2. Performance

Developed algorithm was employed for correlation coefficients computation on images with size 320*240 pixels. Computational cost of our algorithm in millions processor cycles is presented in Table 1. Correlation window size is 3*3 points in this case.

Table 1. Computational cost in millions processor cycles for C implementation and C/MMX/SSE implementation.

Algorithm stage	C	C/ MMX/ SSE	Profit
Dynamic noise reduction	3.5	0.4	8.75
$Vsum$ computation for (3), (4)	4.4	2.8	1.57
$Hsum$ computation for (3), (4)	3.7	2.1	1.76
$Vsum$ computation for (2)	2.5	1.7	1.47
$Hsum$ computation for (2)	2.1	1.1	1.9
Correlation coefficients calculation and maximum coefficients determination	284	16.7	17.6

Total time consumptions for different window sizes are represented in Table 2.

Table 2. Achieved time in ms. for C implementation and C/MMX/SSE implementation.

Window size (L*K)	Number of coefficients per pixel	C	C/ MMX/SSE
3*3	9	119	14
5*5	25	379	42

As evident from results, increasing in performance does not depend on correlation window size. It is so because we use box filtering technique whose productivity is invariant the window size. Factor of productivity rising is approximately 8.5 times in both cases.

To determine accuracy of developed algorithm the coefficients to be obtained were used for optical flow estimation according method described in section 2.4. Fig.3 shows initial frames and obtained optical flow maps. These maps were obtained by using correlation window with size 3*3 pixels. Time consumptions for optical flow computation method are represented in Table 3.

4. CONCLUSION

We have developed fast algorithm to calculate cross correlation function with application MMX and SSE (SSE2) extensions of modern general purposes processors. Obtained results have shown high efficiency of such extensions in the field of computer vision. Our algorithm can be used in other correlation based techniques such as stereo matching, feature detection, object tracking and others.

Table 3. Achieved time in ms. for optical flow estimation.

Frame size	3*3	5*5
640*480	85 (10 fps)	159 (6 fps)
320*240	19 (52 fps)	45 (22 fps)
160*120	4 (250 fps)	7 (142 fps)

We have used our algorithm for optical flow estimation. The experiments allow us to calculate optical flow between frames of video sequence in real time with high frame rate.

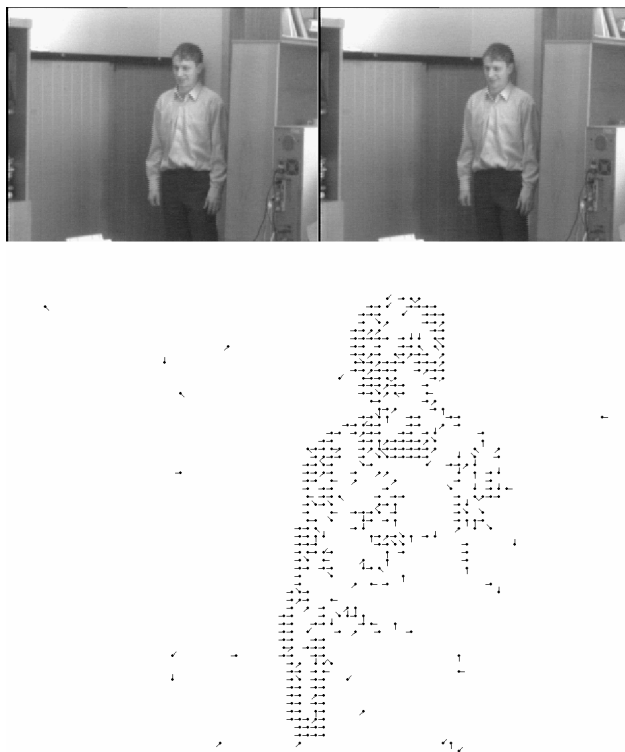


Fig. 3. Optical flow estimation procedure result.

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